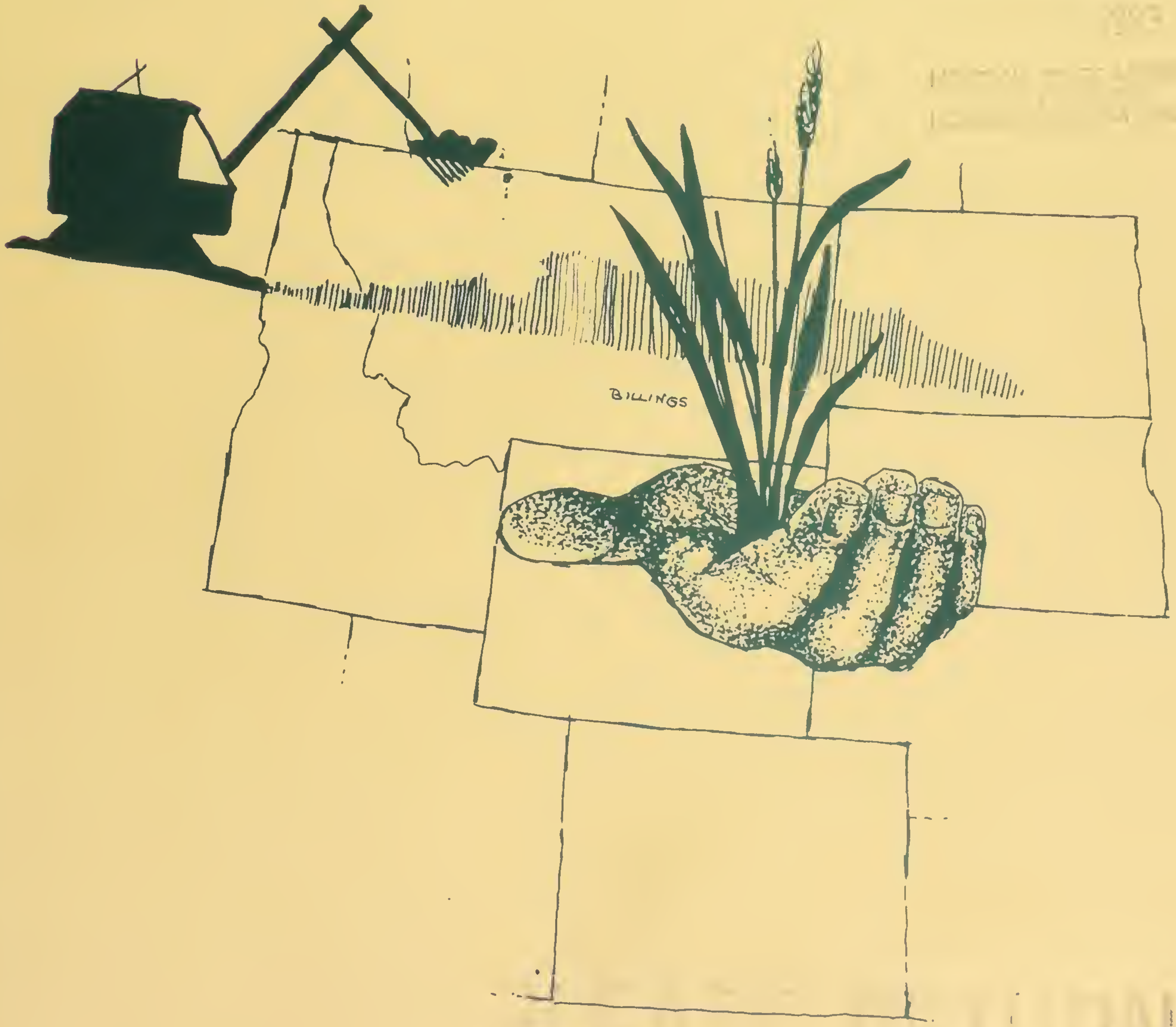
PLANNING, REHABILITATION AND TREATMENT OF DISTURBED LANDS

Sixth Billings Symposium
March 21-27, 1993

Volume I: Tailings, Wastes, and AML Reclamation
Revegetation
Selenium - plants, soils, and reclamation
Acid Forming Materials/Overburden
Cropland Reclamation/Revegetation



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This publication contains the proceedings of the Symposium on Disturbed Land Rehabilitation. Speakers were asked to submit camera-ready copy for this publication. Because of the schedule for printing, the chairmen were unable to edit the texts and apologize for any errors in the copy or poor reproduction of figures or tables.

Several papers were not received in time to be included in this publication; thus, the lack of conformity between the Agenda of the Symposium and this published proceedings was unavoidable.

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Co-Chairman

Planning, Rehabilitation and Treatment of Disturbed Lands

Sixth Billings Symposium
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Volume I

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INTEGRATED APPROACH TO TAILINGS RECLAMATION DESIGN

L.E. Fiske[1], B.L. Carlson[1]

ABSTRACT

This paper provides a general design approach to mine waste reclamation with the goal of reducing long-term post closure liabilities of mine operators. The design approach presented is intentionally broad and general in order to make the concepts relevant to the reclamation of any site.

This paper addresses a four step process which is intended to facilitate the design of a optimum reclamation plan which will is technically sound, regulatorily defensible, and economical.

---

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INTRODUCTION

This paper is intended to provide a general design approach to mine and tailings reclamation. While the design concepts presented are not new or innovative, the critical issue is the overall framework of the design method. The method discussed is a stepwise procedure which addresses aspects of long-term stabilization/remediation with the goal of reducing long-term liabilities of mine operators. The steps involved in reclamation planning can be summarized as follows: 1) identification of regulatory requirements, 2) site characterization, 3) alternative evaluation, 4) preparation of the final reclamation design. It is not uncommon for some of these the steps, particularly site characterization and alternative evaluation, to be omitted from the design process however, if the design process is followed operators will often find that the minimal increase in up-front design cost will be offset by savings in the time required for regulatory review, and the cost of construction.

REGULATORY REQUIREMENTS AND OBJECTIVES

This paper is not intended to specifically present a summary of the regulations as most, if not all, regulations are constantly changing. Additionally, the stepwise design concept presented herein is universally applicable to all reclamation planning whereas many regulations governing reclamation can be both product and geographically specific. However, major regulatory concerns that are consistent with most, if not all, regulations fall into the scope of two broad requirements: environmental protection and land use restoration.

Environmental Protection

The major thrust of all regulations is to isolate mine waste which could have an adverse impact on the environment. Determination of what action is reasonable and what level of impact to the environment is acceptable are the major points of contention between operators, regulators, and special interest groups. The definitions of reasonable and acceptable are different for every mining operation and are dependant on such factors as the type and relative hazard of the waste, the background environmental conditions, and the proximity of the mine to populated areas. Therefore, complete baseline data and characterization of the waste prior to reclamation is paramount to any reclamation design.

From an environmental prospective, there are three major pathways that must be considered in isolating the waste; surface water, groundwater, and air.

Surface Water

Surface water in the area can be impacted by runoff from the reclaimed area. The reclamation plan should include elements that reduce the potential for erosion which could ultimately lead to materials entering nearby surface water via erosion of the waste. This can be accomplished through the use of diversion channels or storm retention basins.

Groundwater

Impacts to groundwater have the potential of being the most difficult to quantify and the most expensive to remediate. Minimizing the potential impacts to groundwater must therefore be a major priority in the reclamation plan. Impacts to the local groundwater system both during operation and long-term after reclamation should be considered. Impacts can be quantified further if baseline water quality data has been established. With established baseline data and existing water quality data, remedial actions can then be identified.

Air

Release of material via this pathway usually results from wind erosion and thus, the reclamation plan should include means to minimize the impacts of wind erosion. The most typical means for preventing wind erosion is the placement of a waste cover system such as a vegetated topsoil layer.

Vegetation however, is not always a viable option for the prevention of wind erosion, especially in semiarid regions which do not support significant plant growth. In cases where climatic conditions support only a sparse plant community, it is typically feasible to provide additional stability to the topsoil by mixing in rock to produce a soil cover similar to a natural desert armor.

Uranium mill tailings are a special case where a gas, specifically radon (a daughter product of radium decay), is released into the atmosphere. Therefore, reducing radon flux from the tailings to regulatorily acceptable levels is a major element of reclamation plans for uranium tailings. The reduction of radon gas release is typically accomplished by placement of a cover system designed to attenuate the release or radon to the required level.

Restoration of Land Use

The other major goal of reclamation is to restore the land to some type of beneficial use. Again, the major point of contention is usually involved with a definition. In this case, what is "beneficial". In may cases, the pre-mining and post reclamation land uses are for grazing and wildlife habitat. If the pre-mining condition of the land was poor because of overgrazing, the question then becomes; "Is the pre-mining condition of the land an acceptable goal for reclamation or is the operator obligated to return the land to a condition that is ideal for the land use even if it is better than the pre-mining condition?" If the latter is the case, the reclamation plan should provide some mechanism, such as site fencing, to prevent overgrazing, until the reclamation bond is recovered.

SITE CHARACTERIZATION

The site characterization is a critical component in reclamation planing. The intent of this investigation is to characterize the waste material and any borrow materials that might be used for reclamation and to determine the existing environmental impacts from the operation. In this regard, a complete data base is critical in order to develop cost effective alternatives for remediation, and to avoid costly down-time to investigate and design for "surprises" after construction mobilization.

In many cases, significant information exists from a variety of sources such as environmental impact statements, ongoing monitoring, and investigations that were performed as part of the design of tailings embankments or heap leach pads. The site characterization study should be designed to fill the data gaps that might exist such as; the physical and chemical characteristics of the waste, available cover soils types and suitability, on-site rock availability, and appropriate revegetation techniques.

Waste Characterization

Additional characterization of the physical and chemical characteristics of the waste materials is usually required. The types of characterization is dependant on the specific requirements and conditions but usually includes information necessary to predict long-term groundwater quality, potential impacts on vegetation, and physical stability of the reclaimed area.

Cover Materials

If a cover system is determined to be appropriate for remediation, the site characterization plan should include the determination of available types and quantities of on-site materials and their suitability to meet the design objectives. These design objectives could include protection from wind erosion, radon attenuation, limiting tailings exposure, plant growth medium, infiltration control, or any combination thereof.

Rock

The site characterization plan should include provisions for the determination of on-site rock availability in cases where rock protection is needed for diversion channel or tailings surface riprap. Additionally, if on-site rock is available, the suitability of that rock in terms of its resistance to weathering and hydraulic degradation should be assessed.

Revegetation

It is often useful to conduct a plant community survey in the vicinity of the site in order to determine the most reasonable course of action toward revegetation of disturbed areas. In many instances, revegetation test plots have been constructed on site to provide the operator with the best information for achieving revegetation success. Test plots also provide regulatory agencies with validity and documentation for the selection of plant species and the assurance that actual on-site data was used in developing the revegetation plan. If the goal for revegetation is to achieve native conditions, it may also be beneficial to establish native reference areas for comparisons with test plots and eventually with the actual revegetated areas.

ALTERNATIVE EVALUATION

A critical step in the selection of a reclamation plan is the alternative evaluation process. In general, there are a multitude of design solutions for any given problem and the design of a mine waste reclamation system is no exception. Too often, it is believed that the best reclamation system for a given site is self evident and therefore little to no consideration is given to alternative courses of action. However, it has been the authors experience that a carefully conducted alternative evaluation process will often lead to a final design which is more economical than the obvious solution and best meets the design criteria.

Some of the considerations typically used to evaluate reclamation alternatives are; cost, constructability, time to completion, regulatory acceptability, and long-term liabilities and maintenance. It is not often that a single alternative will best meet all of these considerations. For example, one alternative may be more difficult to construct than another, but produces a final system with less long-term liabilities and maintenance requirements. Given that there can be many considerations for evaluating alternatives, and typically no single alternative best meets all of the criteria, the alternative evaluation should have some provisions for determining a relative ranking of alternatives. The authors have used such a ranking system in the past and have found that even a simplistic system provides an effective method of evaluating alternatives.

The final result of an alternative evaluation is typically a written document summarizing the merits of each alternative, and giving qualitative or quantitative reasons for the ranking assigned to each alternative. In the end, the evaluation process should produce a preferred reclamation alternative which best satisfies environmental requirements and restores the land to the appropriate use.

Additionally, the completion of the alternative evaluation often provides an operator with an opportunity to obtain input from the regulatory agencies which must eventually approve the final reclamation plan. Furthermore, presentation of the alternatives via an open forum for discussion often gives the operator significant insight into what will be acceptable as a final plan before additional resources are expended on final design of the preferred alternative.

FINAL DESIGN

The final design is the last step in the reclamation planning process. This step is typically the most costly, however, if an adequate alternative evaluation was conducted the final design is generally straight forward. The intent of the final design is to provide a strategic reclamation plan which meets the design objective of environmental protection, and restoration of determined land use.

The final design should contain an appropriate level of documentation regarding how the design objectives will be met in order to obtain approval from regulatory agencies. The final design documents should not consist of construction grade plans and specifications since revisions are to be expected subsequent to regulatory review. However, if the regulatory agencies are allowed or willing to participate in the review of alternatives and be a party to the selection of the preferred alternative, any revisions to the final plan are often minor and concerned with specific details.

Post reclamation monitoring will normally be required to evaluate the success of the established reclamation design. Monitoring usually consists of surface water quality measurements, inspections to evaluate if surface erosion has occurred, observance of any sedimentation, ground water quality measurements, and revegetation measurements to evaluate the success of the established plant community. The monitoring plan should be developed in conjunction with the reclamation plan to selectively design and minimize the amount of post reclamation monitoring.

The goal of the monitoring plan should be to provide regulatory agencies with substantial information that the reclamation as designed is successful, and prevents long-term liabilities and ensuing environmental degradation.

CONCLUSION

The development of a reclamation plan is generally not a difficult process, however, the development of an *optimum* reclamation plan requires a more formal and structured process such as that presented in this paper. While the process presented may appear simplistic and unsophisticated, the important issue is the four step framework for developing the plan. It is very easy to skip some steps such as the site characterization or the alternative evaluation with the goal of producing a reclamation plan at less cost. However, it is our experience that a relatively small increase in the up-front design costs required to perform a rigorous design is more than recovered in significant cost savings in the regulatory review process and construction phase.

Planning, Rehabilitation, and Treatment of Disturbed Lands

Billings Symposium, 1993

JACKPILE RECLAMATION PROJECT--History & Progress Update

by

James H. Olsen, Jr., PE[1]

Abstract

The Jackpile Reclamation Project involves the reclamation of what was once the world's largest surface uranium mining operation. The mine is situated on the Laguna Indian Reservation about 50 miles west of Albuquerque, NM and operated from 1951-1982, producing over 24 million tons of uranium ore and handling almost 400 million tons of overburden and mine material. The reclamation of the site was undertaken by the Pueblo of Laguna in 1989 after the Environmental Impact Statement and Record of Decision were formalized by the Department of the Interior (1985-1987).

The Project has some unique features. It is the largest project of its kind undertaken and is under the direction of the Pueblo of Laguna. Many techniques used on this site may have applications in other situations, i.e., reclamation of metal mines. Particular attention to the environmental and design engineering is achieving Project goals along with cost-effectiveness. The combination of theregulatory and jurisdictional responsibilities has afforded an opportunity to develop a "common sense" approach to dealing with the previously-unregulated metal- mining reclamation area.

The Laguna Construction Company (a State-chartered corporation wholly-owned by the Pueblo of Laguna) is the construction contractor and one of the largest Native American corporations of its kind.

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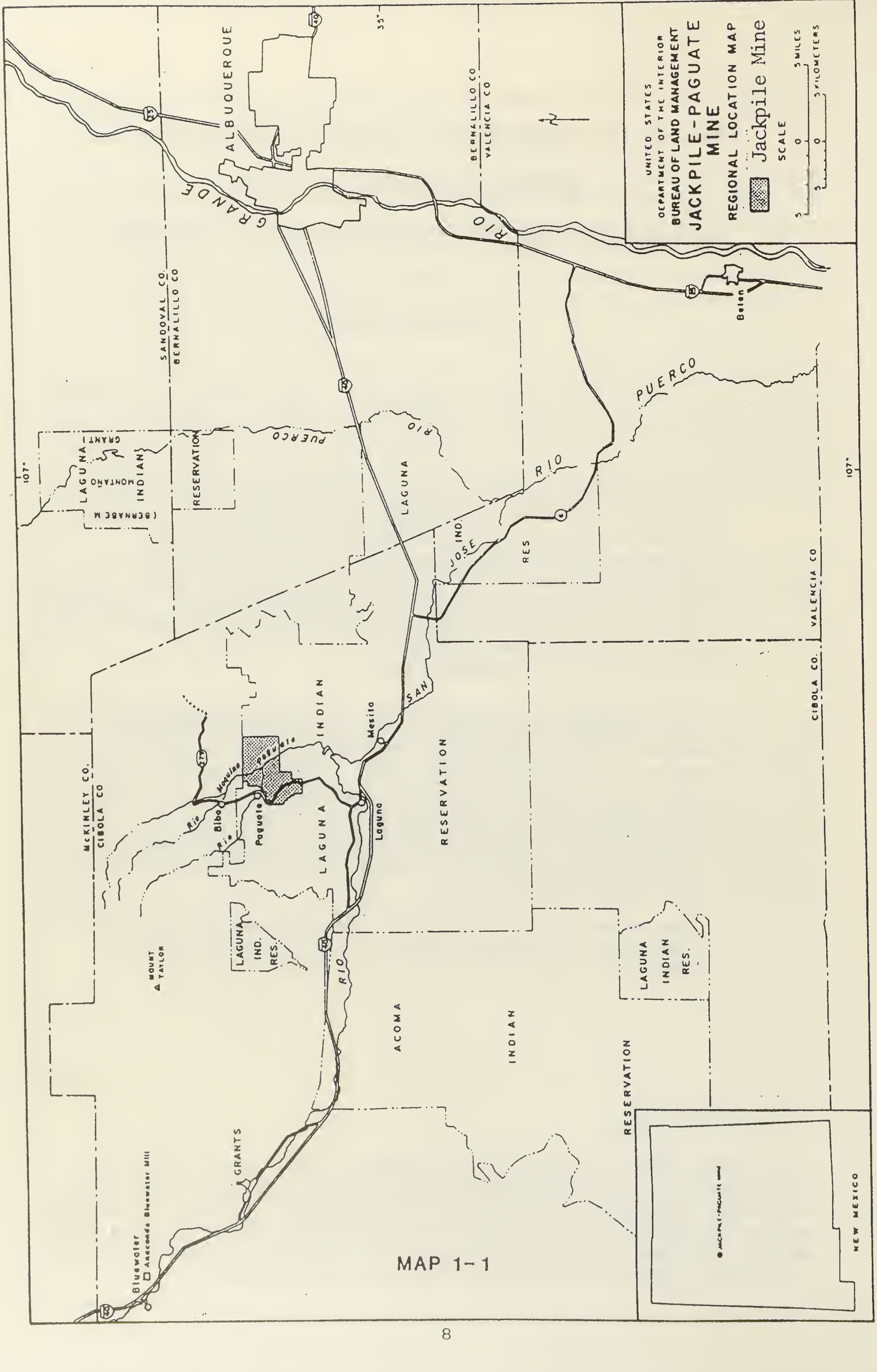
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
JACKPILE-PAGUATE MINE
REGIONAL LOCATION MAP
Jackpile Mine
SCALE
5 MILES
5 KILOMETERS
ALBUQUERQUE
RIO GRANDE
BERNALILLO CO
VALENCIA CO
SANDOVAL CO
BERNALILLO CO
Belen
RIO PUERCO
LAGUNA INDIAN RESERVATION
(BERNABE M MONTAÑO GRANT)
RIO SAN JOSE
IND. RES
LAGUNA
VALENCIA CO
CIBOLA CO
McKINLEY CO
CIBOLA CO
Rio Moquino
Paguate
Rio Bibo
Paguate
Mesita
Laguna
LAGUNA INDIAN RESERVATION
LAGUNA IND. RES.
LAGUNA INDIAN RES.
MOUNT TAYLOR
ACOMA INDIAN RESERVATION
GRANTS
Bluewater
Anaconda Bluewater Mill
NEW MEXICO
JACKPILE-PAGUATE MINE
35°
107°
40
25
25
279
6

MAP 1-1

Jackpile Reclamation Project--*History & Progress Update*

I. Mine History

The Jackpile Mine, located approximately 50 miles west of Albuquerque, NM, is situated on the Pueblo of Laguna. The mine was once the world's largest surface uranium producer and was operated by the Anaconda Company (later merged with Atlantic-Richfield Corporation in the mid-1970's). The Anaconda Company had obtained exploration and mining leases from the Pueblo of Laguna in the early 1950's. Three open pit mines and nine adjacent underground mines operated from 1951 to 1982 when economic conditions and the demand for uranium collapsed. During the active life of the operation, some 24 million tons of uranium-bearing ore were produced and approximately 400 million tons (235 million cubic yards) of ore, mine waste, and overburden were handled during the mining operations. The disturbed area encompassed about 2700 acres. All ore material was shipped off-site for milling and processing, the bulk of which went by rail from the mine site to Anaconda's Bluewater Mill, about 60 miles west of the Jackpile Operations. The uranium was originally sold to the Federal Government under the old Atomic Energy Commission (AEC) provisions. In the 1960's, government controls were eased and private utilities were securing uranium supplies for electrical power generation.

Approximately 650 people were employed in the mines, most of whom were Tribal members. The jobs were in equipment operation, maintenance, administration, engineering & geology, and other support activities. Royalties on the uranium content were paid by Anaconda to the Pueblo of Laguna.

II. Environmental Impact Statement

Given that the mine operation pre-dated the National Environmental Protection Act and the normally-required Environmental Impact Statements, final reclamation of the Jackpile Mine was originally addressed in the late 1970's when discussion among Tribal, Company, and Federal officials began to consider the ultimate disposition of the Site. Specific regulations did not (and still do not as of this writing-1992) exist which would determine the required reclamation criteria for uranium and other metal mines. A nominal bond was in-force as had been required by the Department of the Interior for companies leasing minerals on Tribal lands but it was not felt to be adequate to effectively stabilize the site. The lack of specific regulations further complicated the situation along with some jurisdictional complexities since the site did not fall under the NRC's tailing regulations (i.e., the ore was not processed on the site and thus the materials did not meet the definition of *tailings*); coal mine reclamation regulations did not apply since those are specific to coal strip and surface mines; other waste regulations which may have been in force did not apply to metal mine wastes. The proposals submitted by the Anaconda Company had not been accepted by the Pueblo of Laguna nor the Department of the Interior.

Because of this lack of specific regulations and the desire of the Pueblo of Laguna to assess the impacts and needed action, a formal Environmental Impact Statement (EIS) process was initiated thru the Department of the Interior since they have oversight responsibilities on Tribal Lands.

The lead agency was the Bureau of Indian Affairs (BIA) with technical assistance provided by the Bureau of Land Management (BLM) This step was taken to allow for an objective evaluation of the Tribal, Company, and no-action alternatives for the Site and was an unprecedented action as it related to a previously unregulated area. The "draft" EIS[1] was issued in 1985.

The EIS process culminated in the issuance of the "final" EIS[2] in October, 1986 which included one volume of technical considerations of the six alternatives examined and a second volume of public comments on the proposals.

III. The Record of Decision

Following the completion of the EIS process, the Record of Decision[3] (ROD) was issued jointly by the BIA and BLM in December, 1986. The decision factors identified in the ROD were:

1. Ensure human health & Safety.
2. Reduce the releases of radioactive elements and radionuclei to as low as reasonably achievable.
3. Ensure the integrity of all existing cultural, religious, and archaeological sites.
4. Return the vegetative cover to a productive condition comparable to the surrounding area.
5. Provide for additional land uses that are compatible with other reclamation objectives and that are desired by the Pueblo of Laguna.
6. Eliminate the need for post-reclamation maintenance.
7. Blend the visual characteristics of the minesite with the surrounding terrain.
8. Employ the Laguna people in efforts that afford them opportunities to utilize their skills and train them as appropriate.

The specific actions to be taken included: placing all low-grade ore and contaminated material in the pit bottoms, reducing waste dump slopes to 3:1 (horizontal:vertical), stabilize high walls, seal drill holes and underground mine entries, place topsoil over the disturbed areas, revegetate the area with suitable plant species, and perform environmental monitoring activities (air, soil, water, radionuclide releases, radon-222 concentrations, gamma radiation surveys, etc.) Upon reclamation activity completion, the site is to be monitored for a period of ten years during which the success of the vegetative cover will be evaluated and any corrective measures taken.
Based upon the preliminary cost estimates, a financial settlement was reached between the Pueblo of Laguna and ARCO-Anaconda to cover the costs of the required work.

IV. Cooperative Agreement and Public Law 638 Contract

In keeping with Decision Factor No. 8 (above) and pursuing a course of self-determination, the Pueblo of Laguna chose to take full responsibility for the reclamation work. This would maximize the Pueblo's potential employment benefits and allow for control of the work. In order to formalize this arrangement, a Cooperative Agreement consistent with Public Law 638 was consummated between the Pueblo of Laguna and the Bureau of Indian Affairs. Public Law 638 provides for Tribal entities to contract for various activities between themselves and the Federal "trust agencies". The Agreement basically provides that the Pueblo of Laguna has control of the reclamation funds and all associated work but must use those funds to reclaim the site as per the Record of Decision. The Pueblo of Laguna would manage the Project activities and the Bureau of Indian Affairs would have oversight responsibilities to insure compliance with all the

ROD provisions. The Bureau of Land Management would provide technical assistance to the BIA. The Agreement was signed on March 27, 1987.

The details of the Agreement specified the roles of the participants in the Project as well as the required design work, management structure, reporting schedules (financial, construction progress, environmental monitoring), annual planning and budgeting, contract management, approval processes, and the qualifications of the "key" personnel.

V. Project Management & the Laguna Construction Company

Extensive work was done by the Pueblo of Laguna, its technical subcontractor, and the Bureau of Indian Affairs to develop a detailed management plan for the reclamation work. An unprecedented step was taken by the Pueblo of Laguna in the establishment and incorporation of its own construction company to perform all the required construction activities. The Laguna Construction Company was incorporated in 1988 under the laws of the State of New Mexico as a wholly-owned enterprise of the Pueblo of Laguna. A significant "side benefit" of this step was the continuance of the construction company as a going concern after the reclamation work was performed, thereby providing some longer-term employment opportunities for Pueblo members.

The Pueblo of Laguna, as the owner of the Project, formalized a contract with its wholly-owned construction firm in 1989 to do the work. The Pueblo of Laguna, through its Project Management Office, had direct control and oversight from the Pueblo Governor's Office and the Tribal Council. Hiring preference was afforded Pueblo members, and over 90% of the personnel associated with the construction and project management activities are Tribal members.

VI. Preliminary Technical Design & Project Mobilization

Detailed design work was undertaken by the Pueblo of Laguna thru its technical subcontractor (Jacobs Engineering) in 1988 and the initial design work was completed in August, 1989. This work included preliminary, detailed cost estimate, volumes, and various Project specifications, inspection procedures, health & safety plans, and environmental monitoring/regulatory compliance criteria. The Laguna Construction Company specified and purchased the heavy equipment fleet and support vehicles in the summer of 1989 and all deliveries were completed in the fall. Mobilization work began in August, 1989 to begin dewatering the North Paguate Pit, refurbish the maintenance Shop and Field Office facilities, and hire/train the operating and maintenance personnel. The Mobilization Phase ran through December, 1989 and full-scale earthmoving activities began in January, 1990.

VII. Technical/Design Enhancements

Concurrent with the first year's construction activities, some refinements to the original design concepts were completed jointly by the Pueblo's Reclamation Project Management Office, Laguna Construction Company, and Roy F. Weston Engineering. The goal of this effort was to utilize newer reclamation technologies, specifically in the areas of vegetation specifications[4] and erosion controls[5] and still be applicable within the financial constraints of the Project. Since funding was fixed, the most cost effective approach was paramount to insure that the goals and priority items in the Record of Decision were met. These recommendations and revised specifications were approved by the Pueblo of Laguna Council and the Bureau of Indian Affairs in the Spring, 1990.

VIII. Environmental Monitoring Requirements and Programs

The Jackpile Project addresses several environmental program to insure the construction specifications and long-term goals are met.

a. Ground & surface water monitoring: This program involves semi-annual water quality analysis from the Jackpile formation wells, alluvial wells, and pit bottom monitoring wells in addition to upstream, Project site, and downstream surface water courses. The Rio Paguate and Rio Moquino are low-flow streams which course through the site and discharge into the Rio San Jose which, in turn, empties into the Rio Puerco. The well data includes water levels information to ascertain ground water level recovery and heavy metal & radionuclide content in ground and surface water. Water monitoring will continue into the 10-year monitoring program following completion of the Project. Pit water is used for dust control and no water is discharged.

b. Radon-222 Monitoring: Radon emanations from the low-grade ore and natural Jackpile sandstone outcrops are monitored at 14 locations in and adjacent to the Project site with passive radon detectors which are changed and analyzed on a quarterly basis. In addition, an RGM-2 continuous radon measurement device is used which composites samples taken at five-minute intervals. The RGM-2 unit is next to the North Paguate Pit and about 300 yards from the village of Paguate, NM. The site standard adopted for the Project is 3.5 picocuries/liter. Readings taken since 1989 have shown a site average of just over 1 picocurie/liter and only background levels in the village locations.

c. Personnel Monitoring: All personnel on the project are monitored for radiation exposure through thermoluminescient dosimeter (TLD) badges changed and analyzed on a quarterly basis by an outside radiological laboratory. Maximum exposure to-date have not exceeded 5% of the allowable limits set by the Nuclear Regulatory Commission.

d. Particulate and Meteorological Monitoring: Air particulates for radionuclide concentrations are taken at various locations upwind, inside, and downwind from the site. The data collected since 1989 to the present will be evaluated in a meteorological model to estimate any outside exposures as a check against the predictions made during the EIS analysis. An on-site weather stations is recording temperature, wind speed, wind direction, and precipitation data on a continuous basis.

e. Gamma & Other Radiation Surveys: Final reclaim sites must meet a specification of 28 micro r/hour or less. Natural background in the vicinity was measured at about 14 micro r/hour so the adopted standard for the Project is nominally "two times background or less". The one foot shale cover over the low-grade ore materials achieves this standard and the reclaimed areas are essentially at background gamma levels. Areas are measured with a gamma meter on a 200 ft. X 200 ft. grid pattern and are verified by an outside laboratory. Work sites, shops, offices, and lunch areas are routinely measured by the Reclamation Techs for gamma levels and adjustments made as needed to achieve the "as low as reasonably achievable" goal. Alpha particulate samples are taken on equipment, operator's cabs, and materials released for use off-site. All alpha measurements indicate good house-keeping and well below NRC standards.

f. Vegetation and Soils: Soil analyses were taken in 1990 to determine the best native seed mixture for the site. Two mixes were developed (see Tables 1 and 2) which would be applied depending upon the soil type. Only during the last years of the mining operations had any "topsoil" been stockpiled for future reclamation use. The "topsoil" material is composed of the Cretaceous Tres Hermanos Sandstone and other alluvial

Table 5.3. Seed Mix 2, Rates and Costs - Fine-Textured, Sandy Soils

Genus and Species[a]	Common Name[a]	Seed Mixture (%)	Seeding Rate (PLS)[b] lbs/acre	seeds/ft²	Estimated[c] Cost ($)/Acre
Sporobolus airoides var. Salado	Alkali sacaton	20	2.0	62.0	7.80
Sporobolus cryptandrus	Sand dropseed	10	1.0	128.0	3.00
Oryzopsis hymenoides var. Paloma	Indian ricegrass	15	1.5	8.0	12.38
Bouteloua curtipendula var. Niner	Sideoats grama	25	2.5	8.0	8.13
Bouteloua gracilis	Blue grama	5	0.5	8.2	3.00
Andropogon scoparius	Little bluestem	10	1.0	13.0	2.00
Atriplex canescens	Fourwing saltbush	5	0.5	0.4	1.98
Eurotia (Ceratoides) lanata	Winterfat	5	0.5	1.2	3.75
Melilotus officinalis	Yellow sweetclover	5	0.5	3.0	0.43
	TOTALS	100%	10.0	231.8	$42.47/acre

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[a] Seed types based on Curtis & Curtis Seed Catalog (Curtis & Curtis, Inc. 1989).
[b] PLS - pure live seed.
[c] Estimated costs based on 8/15/90 vendor price quotes (Curtis & Curtis, Inc. 1989).

NOTE: *Festuca ovina duriscula* may be added to this seed mix at 1.0 lbs/acre PLS.

Table 5.2. Seed Mix 1, Rates and Costs - Soil with 20% to 50% Rock in Profile

Genus and Species[a]	Common Name[a]	Seed Mixture (%)	Seeding Rate (PLS)[b] lbs/acre	Seeding Rate (PLS)[b] seeds/ft²	Estimated[c] Cost ($)/Acre
Bouteloua gracilis var. Hachita	Blue grama	30	3.6	59.0	$21.60
Bouteloua curtipendula var. Niner	Sideoats grama	25	3.0	10.0	9.75
Hilaria jamesii var. Viva	Galleta	15	1.8	7.0	45.00
Agropyron smithii var. Arriba	Western wheatgrass	10	1.2	3.0	6.72
Sporobolus airoides var. Salado	Alkali sacaton	10	1.2	37.0	4.68
Atriplex canescens	Fourwing saltbush	5	0.6	0.5	2.37
Melilotus officinalis var. Madrid	Yellow sweetclover	5	0.6	3.6	0.51
	TOTALS	100%	12.0	120.1	$90.63/acre

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[a] Seed types based on Curtis & Curtis Seed Catalog (Curtis & Curtis, Inc. 1989).
[b] PLS - pure live seed.
[c] Estimated costs based on 8/15/90 vendor price quotes (Curtis & Curtis, Inc. 1989).

NOTE: *Andropogon scoparius* may be added to this seed mix at 1.2 lbs/acre PLS.

materials adjacent to the mine site that were tested for a variety of chemical constituents and characteristics during the 1990 test program. In addition, specifications for "interseeding" previously-reclaimed areas were also developed. Soil is placed in a specified 18" thickness and measured with an auger drill on a 200 ft. X 200 ft. grid. Seeding is done with either seed drill or hydroseeding techniques. Seeding is preferred during the cooler fall months (September-November) since this follows the summer rain season when most of the annual precipitation is received. Seeding, however, can be done during the spring months and the scheduling is dependent upon soil moisture conditions. No irrigation is used d ue to the lack of water resources as well as the problem of "die back" when artificial irrigation is stopped. Reliance on natural precipitation made sense since the vegetation must ultimately be self-sustaining. No vegetation analysis has been done to-date since the first seeding work was completed in late 1991. During the monitoring phase, however, the vegetation will be checked for cover density and uptake of any potential heavy metals or radionuclides. Inclusion of a re-forestation program is currently being evaluated in a joint effort between the Reclamation Project Office and the Southwestern Indian Polytechnic Institute. Controlled grazing methods will be examined once the vegetation is judged to be adequately established.

g. Health & Safety Program: A Health & Safety Plan was developed for the Project and approved by the POL-Council and Bureau of Indian Affairs. The program was fashioned after the provisions of the Occupational Safety & Health requirements. All Project personnel have received forty hours of training in an OSHA-certified hazardous waste training program.

h. Other Permits & Compliance Measures: The Site had been cleared archaeological in the late 1970's when the Anaconda Company contracted a study through the University of New Mexico. No work is planned outside the previously-cleared areas requiring further archeologically work or an examination of any threatened or endangered species above that done in the EIS process. A water heater was the only asbestos disposal requiring special treatment and no special Tribal permits for sand & gravel, water well use, or other revocable uses was required. No waters are discharged, negating the need for an NPDES permit. At this writing, there have been no other regulatory compliance requirements placed upon the Project.

IX. Project Progress

From January, 1990 thru November, 1992, (thirty-five months of full scale operations and the end of the third Operating Year) approximately 23 million cubic yards of low-grade ore, contaminated soil, dump sloping and cover material had been handled. About 600 acres had been reseeded. The Project is about sixteen months ahead of the baseline estimate and costs are running about 80% of the estimated amounts. All project technical and construction specifications have been met. At current levels of activity, heavy earthwork and the initial reseeding should be completed sometime in 1994. However, outside work opportunities for the Laguna Construction Company could delay final completion but this is not seen as a difficulty since the priority items have been completed.

X. Post-Reclamation Monitoring

The ROD requires a ten-year monitoring period following the revegetation work. The detailed monitoring program (which is currently under POL-Council and BIA review) specifies the activities, analytical work, reporting, funding, and associated work to evaluate the success of the reclamation effort and also take any corrective actions which may be necessary, i.e., repairs due to erosion, reseeding areas where the initial germination was inadequate, etc. The Pueblo of Laguna will have responsibility for implementing and completing this program with the BIA providing an oversight function. The Post-Reclamation Long-Term Monitoring Program was approved by the Pueblo of Laguna Tribal Council and Bureau of Indian Affairs in late 1992.

XI. Construction/Operations

Given the large volume of material to be handled and the surface area involved, a heavy equipment fleet was selected to meet the varying conditions and design criteria.

Pit dewatering consist of the use of two Gorman-Rupp 3000 gpm pumps powered by Caterpillar 200 kw generators. No dumping of pit waters is done and the water is disposed of via evaporation enhanced by dust control in the earthmoving areas. Three 5000 gallon tankers are used.

Sloping of waste dumps (from the 1.5:1 horizontal to vertical) to the required 3:1 angle is being accomplished with a fleet of Caterpillar dozers consisting of five D8N size and two D9N models. They are equipped with rippers and reclamation blades. Virtually all dozer work has been sloping in a down-ward direction and better-than-anticipated production was realized. "Slot dozing" techniques were used. Many slope lengths exceeded 1000 feet when finished. The weathered shales and sandstone materials, while not particularly dense or hard, did have some large boulders that were encountered periodically.

Handling of low-grade ore and shale/soil cover materials is being accomplished by the scraper and belly dump truck fleets. The length-of-haul dictates the equipment application since the character of the materials is the same for either fleet. The scraper fleet is composed of five Caterpillar 631E models which are "push-loaded" with a D9N equipped with a "push cushion." Scraper hauls are in the range of 3000 feet and grades have been predominantly downhill at 3-5%. The truck fleet handles the longer hauls and is composed of seven 70-ton belly dump trucks pulled by Haulpak tractors. The tractors can be converted to an end-dump configuration, giving them additional flexibility. The belly-dump trailers were fabricated by Mega, Inc. of Albuquerque, NM under Laguna Construction Company's specifications. The trucks are loaded with two Caterpillar 988B model front-end loaders. A Caterpillar D10N dozer loosens the materials in the stockpile source and pushes the material down to the loader locations. Low-grade ore and supplemental backfill materials needed to achieve the required elevation in the pit bottoms are dumped by the scrapers and trucks and then pushed into the pit by two Caterpillar 824C rubber-tired dozers, which also perform cleanup around the area. Grade of the backfill is controlled by a laser unit.

Upon completion of backfilling and sloping of dumps containing uranium-bearing material, cover materials are placed. Prior to placement of the cover materials, the area is disced with a farm disc pulled by a Caterpillar D6LPG dozer. Discing on slopes is done at a 45° angle to the slope direction in order to interrupt any erosional drainage patterns and increase the shear area for the cover materials. This technique was a result of the design analysis on the hydraulic stability of the slopes since they were relatively steep and in some cases in excess of 1000 linear feet. In areas were low-grade ore or uranium-bearing waste was exposed, a 12" thickness of shale is placed. This has been demonstrated both by technical calculation and by actual field measurements to reduce the gamma radiation emissions by an order of magnitude and will also inhibit Radon-222 emanations. Soil cover is then placed over the shale cover to a depth of 18-inches. Cover materials on the sloped areas are typically dumped at the slope crest by either scraper or truck and then spread over the area with the dozers. The required thickness is controlled by survey stakes.

Seeding of the areas upon completion is done by seed drill on the flat and short slope areas; the longer sloped areas are seeded with hydroseeding techniques. No artificial irrigation is used for two reasons: lack of available water for this purpose and the philosophy that the vegetation must establish and sustain itself under the prevailing natural conditions.

In addition to the reclamation activities, other work has included demolition/salvage of old mine structures and fencing of the site to prevent unauthorized grazing/access.

Maintenance effort is supported by two service lube trucks, three maintenance trucks with welding equipment, transport trailers, and a utility backhoe and a small loader/forklift unit.

Operations works one-shift per day, forty hours/week. Maintenance work is staggered during the work day to service equipment during lunch breaks. Equipment availablility has been above 96% for the Project to-date.

XII. Conclusion

The Pueblo of Laguna has achieved considerable success in not only reclaiming and stabilizing the mine site but also in the development of its wholly-owned construction company. Many of the approaches taken on this Project could have application in other situations, especially in arid environments. Unlike some other projects, this one paid considerable attention to prioritizing the effort to address the most important problems in a cost-effective manner. It is important to point out that no financial resources other than those obtained by the Pueblo of Laguna in their settlement with the operating company are being used; the Pueblo took on an unprecedented effort both in terms of the complexity of the Project and complete Tribal control consistent with the ideal of self-determination. The effort has not been without its difficulties but the experiences gained on this Project (environmental, managerial, technical, etc.) may be of value to other situations and an effort is being made to share those experiences.

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CHARACTERIZATION AND RECLAMATION OF COAL TAILING MATERIALS

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ABSTRACT

In October 1988, a research project was initiated to develop an alternative to the existing method for reclaiming areas affected by coal cleaning waste (tailings) disposal at the Luscar Sterco (1977) Limited Coal Valley Mine. The biological component of this study included tailings and soil sampling and characterization, a greenhouse experiment and a field experiment.

The coal tailings were analyzed for several chemical and physical properties, soluble ions in saturated paste extracts, plant available trace elements and total elemental content. The analytical results indicated that in evaluating the coal tailings as a root zone material it would have a “good” rating for most parameters except pH and SAR. For the greenhouse experiment the soil and tailings treatments included control (soil only), waste only, 15 cm soil overlying waste, and a 1:1 mixture of soil and waste. The crops included alfalfa and reed canary grass. For both forage species the highest yield was obtained from the soil over tailings treatment and lowest yield from the tailings only treatment.

In the field experiment four soil replacement over tailings options were utilized including no soil replacement, 15 cm soil, 30 cm soil, and 30 cm soil/105 cm spoil over tailings. Two different seed mixtures were utilized for each of the soil replacement options. Vegetation rooting depth was directly proportional to moisture availability and the coal tailings did not have any negative impact on the rooting characteristics of the vegetation. The plants grown directly on the tailings had tissue elemental characteristics similar to plants grown on the soil treatment plots. The highest forage yield occurred on the 120 cm soil topdressing treatment, however the yield obtained on the 15 and 30 cm soil treatments and directly on tailings was more than adequate to mitigate any site management problems that might occur.

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INTRODUCTION

In October 1988, a research project was initiated to develop an alternative to the existing method for reclaiming areas affected by coal cleaning waste (tailings) disposal at the Luscar Sterco (1977) Ltd. Coal Valley Mine. The mine operations are located approximately 90 km south of Edson, Alberta in the Rocky Mountain Foothills. Previous reclamation practices included capping the tailings with 3 to 6 m of rock overburden to meet operational requirements although only 1.2 m was required by regulation. Research activities included a geotechnical component (Stahl and Sego 1992) and a biological component which is described in this paper. To reiterate the coal tailings discussed in this paper are defined as the reject or waste associated with the coal cleaning process and not overburden materials resulting from coal extraction.

OBJECTIVE

The overall objective of the research project was to develop an alternative to the existing method for reclamation of areas affected by coal tailing disposal that is cost-effective and environmentally sound. The subobjectives of the biological component were as follows:

- determine the physical and chemical properties of the "waste" material by sampling and analytical work;
- assess the growth support capability of the tailings (potential toxicities or any adverse properties) and impact on tissue characteristics (elemental uptake) in a greenhouse experiment in order to provide direction for treatments to be tested in the field;
- determine the effect of different material replacement options on plant growth and tissue characteristics in the field experiment;
- characterize "slack" coal dumps in the area and compare to the tailings material to determine the degree of similarity and potential for extrapolating vegetation performance data from the slack coal areas to the tailings area.

MATERIALS AND METHODS

Sampling

The sampling program completed in October 1988, included acquisition of coal tailings, salvaged soil, and slack coal materials. Tailings placement in the 20 hectare pit at the coal Valley Mine was initiated in 1978 and discontinued in May 1989. A total of 26 solid phase samples representing the 0 to 30 cm, 30 to 75 cm, and 75 to 150 cm intervals were obtained.

The coal slack dumps are comprised of tailings from mining operations that existed some 40 to 60 years ago. A total of 15 coal slack samples were obtained at five individual sites in the area representing the 0 to 30 cm, 30 to 75 cm, and 75 to 150 cm depth intervals.

Greenhouse Pot Trial

The greenhouse pot trial was undertaken to assess the growth support potential of the tailings material and the plant elemental uptake associated with the tailings and soil replaced over tailings treatments.

The soil used in the greenhouse pot trial was obtained from a stockpile located near the offices and processing facilities. The stockpiled material included a mixture of A, B, and C horizon material from Luvisolic and Brunisolic soils occurring in the area.

The major variables in the greenhouse experiment included the soil and tailings treatments, the crop grown and the number of replicates. The soil and tailings treatments included:

- control (soil material only);
- tailings material;
- 15 cm soil overlying tailings material;
- 1:1 mixture of soil and tailings material.

The crops included reed canary grass and alfalfa and each treatment had three replicates.

The pots used were 12.7 cm in diameter and 15 cm in height, lined with plastic bags and kept in saucers throughout the trial. For the 15 cm soil over tailings treatments plastic cylinders 38 cm in height and 12 cm in diameter were used as containers. Prior to planting the individual pots were watered to field capacity and fertilized with a solution which supplied 50 ppm N, 50 ppm P, 50 ppm K, and 15 ppm S.

Fifty seeds of reed canary grass or alfalfa were placed randomly in the respective pots and covered with 1 cm of material. The pots were placed in a random order and positions changed twice thereafter during the experiment.

The greenhouse compartment temperature was maintained between 20 and 25°C during the day and between 15 and 20°C at night. A day length of 16 to 18 hours was achieved by use of overhead lighting and moisture content was maintained at or near field capacity by watering on a pot weight basis twice a week.

At two-week intervals the height of the grass was measured by placing a ruler at the soil surface and reading the average height of the plants. The plants were harvested 1 cm above the surface of the growth medium to minimize potential contamination. The plants were washed in a dilute metal free detergent solution, rinsed three times in distilled water, dried at 70°C for 24 hours and the dry weights recorded.

Following the harvest, the waste/soil mixture was gently removed from the roots. The roots were washed in a dilute metal free detergent solution, rinsed three times in distilled water and towel dried. Weights of the roots were recorded after towel drying and again after drying for 24 hours at 70°C.

Field Trial

Four soil replacement over tailings options were utilized including no replacement, 15 cm soil, 30 cm soil, and 30 cm soil plus 90 cm spoil (parent material) over tailings.

Two different seed mixtures were utilized for each of the soil replacement options.

Mixture 1	
Reed canary grass	60%
Alfalfa	40%

Mixture 2	
Reed canary grass	40%
Timothy	20%
Alsike clover	15%
Red clover	15%
Red top	10%

The plot area was seeded by hand-broadcast at a rate of 60 kg/ha in May 1989. The plots were fertilized with 27-27-0 fertilizer in June and the entire tailings area was seeded with Mixture 2 in July, 1989.

In August 1989, soil samples (0 to 15 cm depth) and plant yield and tissue samples were collected from a number of the plots. In 1990 plant tissue and yield samples were collected in June and soil samples were collected in September.

The surface soil samples submitted to the laboratory represented a composite from five locations for the 0 to 15 cm depth within each treatment.

The tissue samples were obtained by collecting appropriate plant material from several locations within each treatment. The yield samples represented the plant material obtained from a total area of five Daubenmire (1959) frames. A measuring tape was laid out from the NE to SW corner of each plot and the frames were placed at the 2, 4, 6, 8 and 10 m marks along the tape. The grass was clipped at approximately 2 cm above ground level.

A climate monitoring station was installed in the study area on June 15, 1989. One model 824 Easylogger unit was installed which provides the capability of measuring air temperature, soil temperature, rainfall, wind speed and direction, solar radiation, relative humidity, and soil moisture. Precipitation was measured by a tipping bucket rain gauge to provide a measure of rainfall intensity and a Taylor Clear-Vu rain gauge to obtain total values for a specific time frame.

Analytical Methods

This section describes the materials and methods used for analysis of the tailings, coal slack, soils used for the greenhouse pot experiment and collected from the field plots, and the tissue obtained from the pot experiment and the field plots. The analyses undertaken were selected to provide a comprehensive assessment of the characteristics of the tailings, soils and plant tissue.

Tailings and Soil Analyses

Water content of the tailing samples was calculated after drying at 105°C for 24 hours and pH was measured in a paste (Doughty 1941) and in a 2:1 slurry of 0.01 M $CaCl_2$ (Peech 1965). Total carbon content was measured with a LECO CR12 carbon analyser (Leco Corporation 1979) and $CaCO_3$ equivalent by acid dissolution (Bascomb 1961). Saturated pastes were prepared according to the USDA Soil Salinity Laboratory method (USDA 1954; Rhoades 1982); were extracted and the extracts filtered through a 0.45 mm filter and analyzed for pH, electrical conductivity, alkalinity, chloride and for soluble salts (Na, K, Ca, Al, Cr, Fe, V, Ti, Cd, Cu, Pb, Zn, Mn, Mg, Li, Sr, B, Ba, P, S, Mo, Ni, Se, As, Co, Si) using an ARL model 3400 simultaneous Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES). Cation exchange capacity (CEC) and extractable cations were determined by extraction with a normal (1 M at pH 7.0) ammonium acetate solution (Holmgren et al. 1977), where NH_4 ions were determined by a Tecator Kjeltec Auto 1030 Analyser distillation and titration unit and the exchangeable ions by the ICP-AES. The particle size analysis was done using a simplified hydrometer method (Gee and Bauder 1979).

DTPA-NH_4HCO_3 extractable elements (Fe, Cd, Cu, Pb, Zn, Mn, Ca, Mg, Na, K, B, P, Mo, Ni, Se) were determined by the method of Soltanpour and Workman (1981). Total elemental analysis was done by digestion in a CEM microwave digestion system. The procedure used included ashing the material overnight in a 425°C muffle furnace, digestion in a teflon bomb in the microwave oven with 1.5 mL HNO_3, 4.5 mL HCl and 10 mL HF for 10 min at 100% power, 20 min at 50% power, and 10 min at 100% power. The digested solutions were transferred and made up with saturated H_3BO_3 to 50 mL, and the metal concentrations measured using ICP-AES.

Plant Tissue Analysis

The grass samples were digested with a concentrated HNO_3-$HC10_4$ acid mixture in a teflon bomb heated in a CEM microwave digestion unit. The solution concentration of Al, Fe, Zn, Mn, Ca, Mg, Na, K, Sr, P, Ba, Mo, B, S, Si, and As was measured by ICP-AES and Cd and Pb by graphite furnace atomic absorption. Chloride content was determined by the sodium nitrate extraction procedure of Gaines et al. (1984).

RESULTS AND DISCUSSION

Paper length restrictions precluded inclusion of data tables therefore only statistical summaries as part of the discussion are included. Similarly, there is no discussion of the data relative to the coal slack sampling component of the study.

Coal Tailing Materials

The coal tailings were analyzed for several chemical and physical properties, soluble ions in saturated paste extracts, plant available trace elements (DTPA extractable) and total elemental content.

Chemical and Physical Properties

The pH (H_2O) values ranged from 7.9 to 8.6 with a mean value of 8.2. Total carbon ranged from 26 to 48% with an overall mean value of 32%. Calcium carbonate equivalent ranged from 1.4 to 3.9% with a mean value of 2.6%. Acid Neutralizing Capacity (ANC) values which provide an indication of the potential for using the material as a lime amendment ranged from 2.7 to 4.9%. Particle size distribution values varied more widely with the sand fraction ranging from 23 to 61% and the clay from 12 to 44%. Mean values were 49%, 28%, and 23% for the sand, silt, and clay fractions respectively which represents a loam texture.

Comparison of mean values by horizontal position indicated that significant differences occurred for total carbon, total nitrogen, extractable calcium, total exchange capacity, $CaCO_3$ equivalent, and sand, silt, and clay content (Macyk et al. 1990). Comparison of mean values by depth indicated that significant differences occurred only for pH($CaCl_2$).

Saturated Paste Extract Data

Saturated paste extract data for the tailings indicate the magnitude of the soluble components in a saturated solution of these materials and can be used to assess the suitability of these materials for plant growth and the possibility of trace element transport.

The EC values varied from 1.3 to 4.3 dS/m with an overall mean of 2.5 dS/m. The Alberta Soils Advisory Committee (1977, 1987) suggests that no limitations to plant growth occur at EC levels of 0 to 2 dS/m and slight limitations occur at 2 to 4 dS/m. Most of the values obtained were below 3.0 dS/m indicating that EC of the coal tailings would result in slight to no limitation to plant growth.

The sodium adsorption ratio (SAR) values ranged from 5 to 18 with an overall mean of 12. The Alberta Soils Advisory Committee (1977, 1987) presented the following criteria for SAR levels in soils:

	SAR Value
No limitation	<4
Slight limitation	4 to 8
Moderate limitation	8 to 12
Severe limitation	>12

Comparing the data obtained to the criteria described above suggests that the coal tailings could present severe limitations to plant growth. However, the overall impact of these SAR values would be reduced in light of the fact that the mean saturation percentage values for the waste material is about 70%. Comparison of mean values by horizontal position (Macyk et al. 1990) indicated statistically significant differences only for saturation percentage. Comparison of mean values by depth indicated statistically significant difference only for Si.

DTPA Extract Data

The plan available fractions of the coal tailing elements were estimated by DTPA extraction. The chelate extractable elements have been shown to correlate well with plant elements (Soltanpour and Workman 1981).

Comparison of mean values by horizontal position indicated no statistically significant difference for any of the elements (Macyk et al. 1990). Comparison of mean values by depth indicated statistically significant differences in Fe, Cd, Cu, and Mn.

Total Elemental Analysis

The total elemental analysis of the coal cleaning tailings is used to assess the potential for heavy metal and other trace element contamination.

Comparison of mean values by horizontal position indicated statistically significant differences for Al, Cu, Cr, Ni, Li, and Zr (Macyk et al. 1990). Comparison of mean values by depth indicated statistically significant differences for P only. All the values for the various elements reported were within the range of values normally found in soils (Lindsay 1979) except for Ba, Mn, Mo, and P.

RESULTS AND DISCUSSION - GREENHOUSE TRIAL

Trial Treatments

The major variables in the greenhouse experiment included the soil and tailings treatments, the crop grown and the number of replicates. The soil used in the greenhouse experiment was obtained from the soil stockpile containing a mixture of A, B, and C horizon material from Luvisolic and Brunisolic soils. The soil and tailings treatments included:

- control (soil material only);
- tailings material;
- 15 cm soil overlying tailings material;
- 1:1 mixture of soil and tailings material.

The crops included reed canary grass and alfalfa. Each treatment had three replicates.

Plant Growth and Yield Measurements

The results indicated that maximum height achieved for both species occurred on the soil over tailings treatment which could be related to the fact that the soil over waste treatment allowed for more vigorous root development and ultimately enhanced top growth. For reed canary grass the tailings only treatment produced the least growth in terms of height of plants.

The fresh and dry weights of the alfalfa and reed canary grass were determined for each of the treatments. The trends were similar for both forage species. The highest yield was obtained from the soil over tailings treatment followed by soil only, 1:1mixture of soil and tailings, and tailings only. A comparison of the means for the yields obtained indicated that there was no significant difference for the dry weights of alfalfa relative to treatment and some differences for the reed canary grass.

During the course of the experiment notes were kept pertinent to observations made. The alfalfa plants from all treatments did develop nodules. At the time of harvest it was noted that both the alfalfa and reed canary grass were shallow rooted and very easily pulled out from the tailings and 1:1 soil and tailings mixture treatments.

Total Elemental Content of the Plant Tissue

Tissue elemental values were compared to values reported in the literature (Chapman 1966) which represent a very wide range of plants.

Overall, the tissue element levels for alfalfa and reed canary grass were within the intermediate or normal range with a few values in the high range suggesting that the tailing materials did not have a negative impact on the elemental characteristics of the forages.

RESULTS AND DISCUSSION - FIELD TRIAL

Climate Data

The climate monitoring station was installed on June 15, 1989 resulting in a partial record for the 1989 growing season and a complete record for the 1990 and 1991 growing seasons.

All of the data obtained relative to air temperature, relative humidity, solar radiation, wind direction, wind speed, soil temperature and rainfall intensity are currently available in hard copy file form.

All of the data are recorded on a mean value per hour basis with measurements made every 3 minutes and mean values computed and recorded hourly. For example a value recorded at 14:00 hr represents the scans and mean value for the time elapsed between 13:00 and 14:00 hr (Mountain Standard Time).

Precipitation totals for May to October based on 30 years of record from Robb and the Lovett Lookout (20 km and 5 km respectively from the research site) are 437 and 486 mm respectively (Pedocan Land 1984).

A total of 509 mm of rain occurred during the period June 15 to October 26, 1989 which suggests that rainfall in 1989 exceeded the 30-year average for the area. In 1990 a total of 666 mm of precipitation occurred from March 1 to August 31 with 610 mm of this occurring from May 1 to August 31. Monthly totals wee 207 mm, 155 mm, 139 mm and 109 mm for May, June, July and August respectively.

It is interesting to note that on August 15, 1989 a total of 10 mm of rain occurred in 5 min (14:52 to 14:56 hour) and on August 16 a total of 55 mm occurred in a 24-hour period. A one in 10-year storm event for the area is defined as 86 mm of precipitation in a 24-hour period (C. Brinker, personal communication). A total of 226 mm of rainfall occurred in 19 days in 1989.

Table 1. Yield (g) of Forage Collected from the Field Trial Plots in 1991.

Field Sample Number	Forage Mixture	Soil Treatment	Weight (g)
LY1	2	120 cm soil	116
LY2	1	120 cm soil	136
LY3	2	120 cm soil	111
LY4	1	120 cm soil	100
LY5	2	30 cm soil	128
LY6	1	30 cm soil	62
LY7	2	30 cm soil	90
LY8	1	30 cm soil	35
LY9	2	15 cm soil	93
LY10	1	15 cm soil	61
LY11	2	15 cm soil	53
LY12	1	15 cm soil	88
LY13	1	0 cm soil	81
LY14	1	0 cm soil	84
LY15	1	0 cm soil	78
LY16	1	0 cm soil	43
LY17	1	0 cm soil	154

The results presented in Table 1 indicate that growth (yield) was greatest on the 120 cm soil/spoil over waste treatment and that Mixture 2 produced more plant material than Mixture 1 for the 30 cm soil treatments.

Plot Yield

Yield of the forage crops was assessed by harvesting material as outlined earlier. The crops included reed canary grass and alfalfa (Mixture 1) and red top, alsike clover, timothy, reed canary grass and red clover (Mixture 2). The yield (dry weight) of the samples obtained in 1991 is presented in Table 1.

It is obvious that the best cover or yield was achieved on the 120 cm soil topdressing treatment, however the growth achieved on the 15 cm, 30 cm soil treatments and directly on the coal tailing was more than adequate to mitigate any problems that might occur with wind erosion etc.

Rooting Depth

Rooting depth was assessed at four locations including the 30 cm topdressing, 120 cm topdressing and no soil topdressing treatments. Maximum rooting depth ranged from 60 to 90 cm in the no soil topdressing area and from 75 to 140 cm in the 30 cm soil topdressing and 120 cm soil topdressing treatments respectively. It appears that the reed canary grass roots penetrated to greater depths than the other species utilized.

At each of the pits free standing water began to accumulate at the 80 to 100 cm depth below the surface of the coal waste material. Therefore, in the plot treatment with a 30 cm soil topdressing the water was accumulating at about 110 to 120 cm below the soil surface.

These observations indicate that rooting depth is directly proportional to moisture availability and that the coal tailing materials do not have a negative impact on the rooting characteristics of the vegetation grown thereon.

Tissue Analysis

The data obtained for the total elemental content of the tissue were compared with tissue values pertinent to various legumes and grasses as reported by Jones Jr. et al. (1991) and Chapman (1966). Jones Jr. et al. (1991) use the terminology "low", "sufficient", and "high" whereas Chapman (1966) uses "low", "medium", and "high" to describe elemental levels in the plant tissue.

In general the data reported indicated differential uptake for grasses and legumes relative to the specific elements. Furthermore the tissue from plants grown on a soil topdressing treatment may have had higher or lower levels of individual elements than plants grown directly on the coal tailings.

In summary the tissue elemental data indicated that for specific elements such as Sr and Zn the levels were nearer to or in the sufficient range for plants grown on the coal tailings than for plants grown on the soil treatments. The reverse was true for tissue Cu levels.

It was apparent that plants grown directly on the coal tailings materials had tissue elemental contents that were: lower than those grown on the soil treatments (Ba, Cu, P, S); higher than those grown on the soil treatments (Al, Cl, Na, Ni, Si, Sr, Zn) and; similar to those grown on the soil treatments (Ca, K, Mg, Mo, Mn).

CONCLUSIONS

1. The SAR levels in the coal tailings appear to be the most limiting, however, it is likely that with time sodium will be leached downward, thereby reducing the limitation.

2. In the greenhouse setting the highest yield was obtained from the soil over waste treatment followed by soil only, 1:1 mixture of soil and waste, and lowest yield from the waste only treatment. The tissue elemental levels in the reed canary grass and alfalfa indicated that forage grown in the tailings or other treatments containing tailings was not adversely affected in terms of elemental content or uptake.

3. The highest forage yield occurred on the 120 cm soil topdressing treatment, however the yield obtained on the 15 cm and 30 cm soil treatments and directly on the coal tailings was more than adequate to mitigate any problems that might occur. In fact, the yield for forage on the coal tailings exceeded the yields achieved in the areas with 15 cm and 30 cm of replaced soil.

4. Vegetation rooting depth was directly proportional to moisture availability and the tailings did not have any negative impact on the rooting characteristics of the vegetation grown thereon.

5. The plants grown on the coal tailings had tissue elemental characteristics that were generally similar to plants grown on the soil treatment plots.

The specific items addressed above indicate that the coal tailings are capable of supporting adequate vegetation cover and that the tissue characteristics of the cover are comparable to that of vegetation grown on areas with a soil topdressing.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

VEGETATIVE RESPONSE AND METAL ACCUMULATION IN GRASSES AND LEGUMES GROWN ON ORGANICALLY AMENDED LEAD-ZINC CHAT TAILING

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ABSTRACT

The U.S. Bureau of Mines is evaluating vegetative responses, plant trace element concentrations, and trace element concentrations in abandoned lead-zinc chat tailing amended with organic residues as a means of mine waste stabilization to prevent the movement of trace element contaminates. Two sets of 121 separate plots were constructed in the greenhouse. Chat tailing from the Cherokee County Superfund site in southeastern Kansas and place in each plot to a depth of 20 cm. A 4X3X3X2 unbalanced factorial experiment was initiated in August 1990. Four organic waste materials were applied at three rates with and without inorganic fertilizer. Control plots were included in the design. All experimental plots were seeded with a mix of introduced and native grasses and leguminous forbs. One set of plots was mulched with prairie hay, while the other set was seeded with milo. Milo increased germination, viability, and total number of individuals and species with no effect on plant biomass. Prairie hay mulch reduced germination and viability, but had no effect on plant biomass. Fertilizer rate had no effect on germination, viability, or plant biomass. Overall growth was greatest with composted cattle manure, spent mushroom compost, and composted yard waste and least in control plots and those amended with turkey litter. Germination and viability were reduced by turkey litter, but not affected by composted cattle manure, spent mushroom compost, or composted yard waste. Trace element concentrations, particularly Cd, Pb, and Zn, were significantly higher in root tissues than in aboveground plant tissues.

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THE USE OF MUNICIPAL COMPOST IN THE REVEGETATION OF A HIGH ELEVATION GOLD MINE

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ABSTRACT

Mining in alpine and subalpine areas frequently results in surface soil coverings of spoil and overburden that differ substantially from pre-mining soils. These severely disturbed sites frequently require amendments to accelerate the development of desirable nutrient cycles and to provide a hospitable growing medium for plants. Composted municipal wastes are becoming more available as greater emphasis is placed on waste reduction at the community level. A market for these waste-generated compost products may be found in the reclamation of disturbed areas. This project evaluated the effects of two types of composted municipal waste and a commercial nitrogen fertilizer on plant establishment, cover, and production. The study site is located at a heap leach gold mine at an elevation of 2,300 meters, 25 kilometers southwest of Helena, Montana. Square plots (3 by 3 meters) were established in a randomized block design. Nine treatments and two controls per block were replicated three times, producing a total of 33 plots. Seedling density, vegetative cover, and production were determined over two growing seasons. Field work was completed in September, 1992. Plots treated with EKO sludge compost and Bozeman municipal yard waste compost produced significantly greater plant density, cover, and production than the two rates of commercial nitrogen fertilizer and the unamended top soil treatment. Compost incorporated into the surface horizon produced significantly greater plant cover and production than surface applications. After two growing seasons total grass cover and production were greater with incorporated EKO compost treatments, while forb cover and production were significantly higher with incorporated Bozeman compost. Results from this field study suggest that composted municipal wastes enhance the establishment and growth of herbaceous cover on this disturbed high elevation site.

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INTRODUCTION

Hard-rock mining in alpine and subalpine areas frequently leaves spoil materials and overburden on the soil surface. These materials can differ substantially from pre-mining soils. Removal of developed surface horizons generally results in spoil material that is both low in organic matter and high in bulk density (Chambers 1987). Numerous studies have demonstrated that amending soils with organic materials such as sewage sludge and municipal waste compost increases soil organic matter content, and improves soil structure and long-term fertility (Joost et al. 1987; Khaleel et al. 1981; Seaker et al. 1988). These municipal wastes have been successful as organic amendments in minespoil and Superfund site reclamation at low elevations in the eastern United States (Garvey et al. 1992; Plass 1982; Skousen 1988).

Composted municipal wastes have not been thoroughly tested in arid regions or high elevation environments of the Western United States (Brandt et al. 1991; Chambers 1988; Fresquez 1989). Researchers studying revegetation techniques at molybdenum mines above timberline in Colorado found the most economical and beneficial soil amendments to achieve sustainable vegetative cover were applications of sewage sludge mixed with woodchips (Brown 1976). Although applying sludge and woodwastes at high elevations has been successful in revegetating mine spoils, nitrogen levels must be carefully balanced to prevent soil microbes from competing with plants for nitrogen during the decomposition process. Composting the sewage sludge and wood wastes at lower elevations could speed decomposition and eliminate some fluctuation in nitrogen cycling (Norland et al. 1991).

The growth and development of municipal composting facilities has expanded rapidly in recent years as community leaders across the country search for ways to reduce solid waste and increase the life of dwindling landfill space. Commercial composting operations have proven to be a cost effective and environmentally sound recycling technology (Goldstein et al. 1992; Steuteville 1992).

The purpose of this study was to evaluate the effects of two types of municipal compost and a commercial nitrogen fertilizer on vegetative establishment and production at a high-elevation site disturbed by mining.

METHODS AND MATERIALS

Site Description

The Basin Creek gold mine, a heap leach operation, is located approximately 25 kilometers southwest of Helena, Montana. Operational life of the mine will result in the disturbance of approximately 156 hectares. The mine includes public and private land in the Deerlodge and Helena National Forests and straddles the continental divide at elevations from 2,260 to 2,380 meters. Soils are primarily gravelly and sandy loams with pH values from 4.5 to 7.5. The subalpine site is dominated by dense stands of lodgepole pine (Pinus contorta), with common beargrass (Xerophylum tenax) and grouse whortleberry (Vaccinium scoparium) being the predominate ground cover. Mean annual precipitation averages 30 inches (760 mm) per year.

Field Plot Design

In late June of 1991 project implementation began on a 0.5 hectare area of the mine, that was previously used as a haul road. The area was recontoured to a 1-8% grade with a southwesterly exposure, and salvaged topsoil was spread over the area to a depth of 15 to 20 cm (6 to 8 in). Plots with dimensions of 3 by 3 meters were established in a randomized block design. One meter buffer zones were maintained between all plots. Nine treatments and two controls per block were replicated three times, producing a total of 33 plots.

Seed Mix and Rate

The plots were rototilled to a depth of 7 to 10 cm (3 to 4 in) for seed bed preparation. All plots were broadcast seeded by hand with the Basin Creek Mine seed mix (Table 1). Seed was lightly raked into the amended surface soil.

Table 1. Species and seeding rates applied in June 1991 on test plots at the Basin Creek Mine.

Species	Scientific Name	lb/a[1]	kg/ha[1]
streambank wheatgrass	Agropyron riparium	7.00	7.84
slender wheatgrass	A. trachycaulum	2.50	2.80
redtop	Agrostis alba	0.25	0.28
meadow foxtail	Alopecurus pratensis	2.50	2.80
mountain brome	Bromus marginatus	3.50	3.92
tufted hairgrass	Deschampsia caespitosa	0.50	0.56
tall fescue	Festuca arundinacea	3.50	3.92
sheep fescue	F. ovina	1.25	1.40
canada bluegrass	Poa compressa	0.25	0.28
cicer milkvetch	Astragalus cicer	1.25	1.40
birdsfoot trefoil	Lotus corniculatus	1.25	1.40
white dutch clover	Trifolium repens	1.25	1.40
	Total	25.00	28.00

[1] Pure Live Seed

Treatments

EKO compost is produced commercially in Missoula, Montana. The compost operation is located adjacent to the municipal sewage treatment facility and utilizes sewage sludge combined with wood product wastes and yard debris. The three phase composting process is completed in 9 months. The final product is screened; 1 cm (0.38 in) for gardening, 2.2 cm (0.88 in) for mining and a double 1 cm (0.38 in) screening for hydromulchers. Mine compost was transported in cubic yard bags to the mine site.

EKO compost was applied at two rates, 76 Mg/ha (68 yd^3/a) and 152 Mg/ha (136 yd^3/a). This is equivalent to compost being spread at 1.25 cm (0.5 in) and 2.5 cm (1 in) thick over the surface of the plots. Two compost rates were surface applied and two rates were incorporated to a depth of 7.5 cm with a rototiller.

Bozeman Compost is produced by the municipality of Bozeman, Montana at the local landfill. The compost used in this study was made up of an estimated 30% grass clippings, 30% leaves, and a 40% combination of straw, hay, manure, hedge trimmings, and wood chips. Finished compost is produced in 20 months and is provided free to the public or used as a soil amendment in rehabilitation of the landfill site.

Bozeman compost, like EKO, was applied at two rates; 76 Mg/ha (68 yd^3/a) and 152 Mg/ha (136 yd^3/a). This is equivalent to the compost being spread 1.25 cm (0.5 in) and 2.5 cm (1 in) thick over the surface of the plots. The compost was incorporated to a depth of 7.5 cm with a rototiller and no surface applications were made.

Mine Combo is a an amendment Basin Creek Mine applies with a hydromulcher for its revegetation projects. A hydromulcher was not available for this study, consequently replicated amendment rates were surface broadcast by hand.

Mine Combo amendments consist of EKO compost double screened through a 1 cm mesh and hydromulched at 9.5 Mg/ha (8.5 yd^3/a). This is equivalent to compost being spread 1.6 mm (0.06 in) over the surface of the plots. Pro-Rich dehydrated poultry waste and Silva-Fiber, a wood fiber mulch, were combined with the compost. Application rates were 112 kg/ha (100 lbs/a) Pro-Rich 14-5-5 dehydrated poultry waste and 2.2 Mg/ha (2,000 lbs/a) of Silva-Fiber.

Rates of ammonium nitrate (34-0-0) were based on the total Kjeldahl Nitrogen (TKN) analysis of EKO Compost (0.7%). Fertilizer was broadcast by hand and raked into the surface at 0.51 Mg/ha (455 lbs/a) and 1.02 Mg/ha (911 lbs/a). These rates are equivalent to the TKN present in the 76 Mg/ha and 152 Mg/ha EKO compost rates.

Two controls were used. One had no amendments or seed and the other control had Basin Creek seed mix broadcast by hand and raked into the salvaged topsoil with no amendments.

Table 2. Treatments and amendment rates applied at Basin Creek Mine study site in June 1991.

Treatment	Amendment Rate	Method
EKO 1I	2.50 cm	Incorporated
EKO 1S	2.50 cm	Surface
EKO 1/2I	1.25 cm	Incorporated
EKO 1/2S	1.25 cm	Surface
BOZ 1I	2.50 cm	Incorporated
BOZ 1/2I	1.25 cm	Incorporated
MINECMBO	Basin Reveg Mix	Surface
FERT 1	NH_4 NO^3 1.02 Mg/ha	Surface
FERT 1/2	NH_4 NO_3 0.51 Mg/ha	Surface
CONT I	No amendments, No seed	None
CONT II	No amendments, Seeded	None

Data Collection

Seedling density was examined at three to six week intervals in July, August, and September 1991. Density was estimated by counting seedling numbers in ten 20 by 50 cm frames located along a diagonal transect in each plot. Plant cover was determined in late September 1991, July 1992, and September 1992 using a modification of the Daubenmire technique (Daubenmire 1959). Cover was estimated in ten frames systematically selected along a transect within each plot. Above-ground plant production was determined in September 1992 by clipping above-ground biomass in five 20 by 50 cm microplots located along a transect in each test plot.

Statistical Analysis

All data sets were analyzed using a one way analysis of variance comparison test on means. Extreme values in some data sets necessitated the use of square root transformations to meet the normality of the residuals. Multiple mean comparison was based on Least Significant Differences (LSD) at a significance level of 0.05.

RESULTS AND CONCLUSIONS

Density

In September 1991, grass and forb seedling density was significantly higher on the Mine Combo treatment than on all other treatments. Compost treatments had significantly greater grass and forb seedling densities than the controls and fertilizer treatments (Table 3).

Table 3. Seedling density (plants/m^2) for grasses and forbs in September 1991 (N=15).

	Grass Seedlings			Forb Seedlings	
Treatment	Mean[1]	Trans[2]	Treatment	Mean[1]	Trans[2]
MINECOMBO	301	5.2a	MINECOMBO	94	2.6a
BOZ 1I	233	4.6ab	Boz 1I	54	2.0ab
EKO 1I	218	4.5ab	EKO 1/2S	48	1.8b
EKO 1/2S	190	4.2b	EKO 1/2I	41	1.7bc
EKO 1/2I	185	4.0b	Boz 1/2I	40	1.6bc
EKO 1S	178	3.8b	EKO 1I	33	1.6bc
BOZ 1/2I	170	3.9b	EKO 1S	15	0.9cd
Cont II	97	3.0c	CONT II	5	0.5d
FERT 1/2	41	1.9d	FERT 1	0	0.0d
CONT I	33	1.6d	FERT 1/2	0	0.0d
FERT I	30	1.4d	CONT I	0	0.0d

[1] True seedling density mean per square meter.
[2] Square root transformation of true microplot mean. Transformations followed by the same letter in the same column indicate no significant difference (P=0.05).

Cover

The following data refers to September 1992 measurements. Bozeman compost applied at a rate of 2.5 cm (1 in) and incorporated 7 to 10 cm (3 to 4 in), yielded vegetative cover that was significantly greater than the other treatments. Incorporated Bozeman and EKO compost treatments had a greater percent cover than surface compost applications, fertilizer treatments, or the controls. Total grass cover on EKO compost 2.5 cm (1 in) incorporated compost plots was significantly higher than on the other plots. Total forb cover was significantly greater on plots with 2.5 cm (1 in) of incorporated Bozeman compost (Table 4).

Table 4. Vegetative cover for grasses and forbs in September 1992 (N=15).

Treatment	Total Cover(%)	Treatment	Grass Cover(%)	Treatment	Forb Cover(%)
BOZ 1I	50.5a[1]	EKO 1I	39.1a	BOZ 1I	29.9a
EKO 1I	40.1ab	EKO1/2I	26.1ab	BOZ1/2I	11.4b
EKO1/2I	28.9bc	EKO 1S	25.1ab	EKO1/2I	2.8b
BOZ1/2I	26.6bc	BOZ 1I	20.6bc	EKO 1I	1.5b
EKO 1S	25.3bc	MINECMB	20.1bc	MINECMB	0.8b
MINECMB	21.0bcd	EKO1/2s	18.9bc	EKO1/2S	0.3b
EKO1/2S	19.7bcd	BOZ1/2I	15.3bc	FERT1/2	0.1b
FERT1/2	11.7cd	FERT1/2	11.5bc	EKO 1S	0.0b
FERT 1	7.9cd	FERT 1	7.9bc	FERT 1	0.0b
CONT II	4.5cd	CONT II	4.5bc	CONT II	0.0b
CONT I	0.6d	CONT I	0.6c	CONT I	0.0b

[1] Means followed by the same letter in the same column indicate no significant difference (P=0.05)

Production

Bozeman incorporated compost applied at the 2.5 cm (1 in) rate had significantly greater production in September 1992 than any other treatment. EKO 2.5cm and EKO 1.25cm (1 in and 0.5 in) incorporated compost along with the EKO 2.5cm (1 in) surface application rate had significantly higher total production than all remaining treatments (Table 5).

Table 5. Total plant production (kg/ha oven dried weight) collected in September 1992 (N=15).

Treatment	Plant Production kg/ha	Treatment	PlantProduction Transformation
BOZ 1I	760a[1]	BOZ 1I	2.64a[2]
EKO 1I	534ab	EKO 1I	2.24ab
BOZ1/2I	391bc	BOZ1/2I	1.72bc
EKO 1S	265bc	EKO 1S	1.42bcd
EKO1/2I	251bc	EKO1/2I	1.41bcd
MINECMB	173c	EKO1/2S	1.08cde
EKO1/2S	150c	MINECMB	1.05cde
FERT1/2	75c	FERT1/2	0.68def
FERT 1	67c	FERT 1	0.54def
CONT II	9c	CONT II	0.15ef
CONT I	3c	CONT I	0.05f

[1] True mean of total plant production.

[2] Square root transformation of true mean. Means and transformations followed by the same letter in the same column indicate no significant difference (P=0.05).

Summary

The EKO compost and Bozeman municipal lawn waste compost produced beneficial effects on plant density, cover, and production at a high elevation mine site. Plots treated with two heavy rates of commercial nitrogen fertilizer and plots receiving unamended top soil had significantly lower plant density, cover, and production. Incorporating the compost 7.5 cm into the surface horizon produced significantly greater vegetative response during the second growing season than surface applications. Surface applied compost was prone to erosion and failed to alleviate a soil crusting problem at the Basin Creek Mine. Total grass cover and production were greatest with incorporated EKO compost. Forb cover and production were significantly higher on plots in which Bozeman compost was incorporated. Results from this field study suggest that composted municipal wastes enhance the establishment and growth of herbaceous cover on this disturbed high elevation site.

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WYOMING ABANDONED MINE LAND PROJECTS IN THE GAS HILLS URANIUM MINING DISTRICT

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ABSTRACT

Underground and open-pit uranium mining has been intensive in the Gas Hills Uranium Mining District since the 1950s and continued into the early 1980s. The district is situated near the southern end of the Wind River Basin and contains four distinct mining areas and approximately 140 square miles of disturbed lands. Prior to the mid 1970s, the mining was conducted with very little environmental regulation. The legacy that 35 years of mining has left is that of massive pits with highwalls hundreds of feet high, sealed off drainages, barren slopes, and water unsafe for any use. In 1987, the Wyoming AML Program inventoried the Gas Hills disturbances, determined eligibility of sites, and prioritized sites for AML reclamation. A total of 69 sites were determined to be eligible for AML reclamation. To date, the Wyoming AML Program, utilizing 7 consulting engineering and environmental teams, has designed 12 separate reclamation construction packages. Nine of these reclamation projects have been completed and three are awaiting further AML funding.

The mining has occurred along uranium roll fronts associated with the upper portions of the Wind River Formation. The Upper Wind River Formation consists of clastic sediments dominated by pyritic sandstones and alternating beds of siltstone and conglomerates. The radiological parameters of concern are uranium and its daughter product, radium-226. These radiological products are highly regulated and are the primary environmental concern for reclamation. Extensive analyses has produced a cleanup level of 20 pico curries per gram (pCi/g) for radioactive products in the Gas Hills. Numerous field and laboratory methods are used for characterization of the radioactive waste. These methods include downhole gamma readings for drill holes, surface gamma readings with scintillometers, beta gamma assessments, and laboratory chemical analyses. All waste exceeding 20 pCi/g is buried above any water table and generally at least 10 feet below the final reclamation surface.

In addition to the radioactive waste problems, the Wind River Formation also has other characteristics which significantly affect the potential for successful reclamation. A significant portion of the waste is pyritic and has tremendous acid generating capabilities. The acidic waste affects the final surface reclamation when acidity is generated near the

final seedbed. In addition, many of the mined pits contain water and are evaluated for potential as a wetland resource. However, weathering of the acidic overburden and waste has often created extremely low pH groundwater in the pits and renders them useless for livestock or wildlife. The Wyoming AML Program has adopted acid weathering techniques, rather than acid-base accounting, as the primary laboratory tool for characterizing the acid generating characteristics of the spoil. Several metals, including selenium, arsenic, boron, and molybdenum are also present in these materials. However, since they occur along the edge of the uranium role front, they are associated with the radioactive elements and any problem associated with these metals are eliminated when the radioactive waste is buried.

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GROWTH OF VEGETATION ON ASH DISPOSAL PONDS

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ABSTRACT

Ash disposal ponds are a growing disturbance on the landscape. As power plants are placed further from population centers, the opportunities to utilize fly ash are fewer and the size and number of disposal ponds increases. To meet growing demands on landscapes, these waste disposal areas must be returned to productive use after they have been filled with ash. This study evaluated various thicknesses of overburden and topsoil over a six inch diffusion barrier as a plant support medium.

In a two year study, seeded perennial grasses performed satisfactorily (cover and production comparable to native rangeland) in all soils over 24 inches thick over ash or diffusion barrier. Production and cover were also adequate in the site covered with 12 inches of overburden and 6 inches of topsoil over the diffusion barrier. The permanence of the vegetation on these sites, the composition of the communities, and salt movement should be continuously monitored on these plots. These data are necessary to develop a reclamation plan for the entire ash pond.

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INTRODUCTION

The material in ash disposal ponds near Colstrip, Montana contains large quantities of salts, especially boron salts. The pH of the material on which the study was established was not restrictive to plant growth (7.6 to 7.7), and the salinity of the ash (3.0 to 3.4) was not phytotoxic but boron in the ash is inhibitory to the growth of some plants. Earlier analyses by the Montana Power Company (1980 analyses) revealed salinity values up to 12.6 mmhos/cm in water in the ash disposal pond and boron concentrations up to almost 100 μg/g (Munshower and Neuman 1981). These levels were not recorded in the dry ash now in the disposal pond.

The most common practice for revegetating and returning these wastes to a productive capacity is to cap them with an impermeable clay liner, cover the liner with several feet of coversoil, place topsoil over the coversoil, and seed into the topsoil. This practice is very expensive and there are indications that this may not be necessary.

The function of the clay cap is to prevent moisture from penetrating the ash. The topsoil and coversoil support the plant community. The depth of the coversoil and topsoil are of major importance because of their expense. Even in semiarid regions vegetation may be established in as little as 18 inches of coversoil or topsoil. However, these plant communities are composed of only a few grass species. Soil covers, therefore, should be deeper than 18 inches but each additional soil increment increases rehabilitation costs.

Extensive observations around the edge of the ash disposal pond have shown that the ash is not as inhibitory to plant growth as many other wastes (e.g., tailings, pyritic waste rock, abandoned bentonite waste). Certain species were observed with roots in mixtures of ash and native soil. It has been hypothesized that, if salt movement into the overlying soil layer could be prevented, a number of plant species could be seeded into a relatively thin coversoil and, if properly selected, several of these plants would root into the ash.

If these species can be induced to grow roots in the ash itself, the deeper root zone will stimulate the development of more complex grassland communities and increase the longevity of the seeded species. If salts do not contaminate the surface soil, the seeded species and volunteering species from the surrounding ecosystem may form a permanent, self-perpetuating plant community.

The problem, therefore, becomes one of preventing salt transport from the ash into a relatively thin surface soil layer. Diffusion barriers have been used to prevent salt movement from lower soil layers into surface soil horizons (Cedergren 1989). This study investigated the use of a diffusion barrier constructed of locally available material and covered with various depths of coversoil and topsoil to support plant growth.

OBJECTIVES

Permanent reclamation of the ponds in an economic manner is the objective of this study. Specific aims are listed below.

1. How much soil is necessary over the ash to permit establishment of a permanent vegetation cover?
2. Is a diffusion barrier necessary to prevent movement of salts into the coversoil?
3. Is topsoil necessary over the soil layer to provide an adequate plant growth medium?

STUDY DESIGN

The study was laid out on an arm of Unit 1 and 2 Ash Disposal Pond northwest of the Colstrip Power Plants. Treatments included:

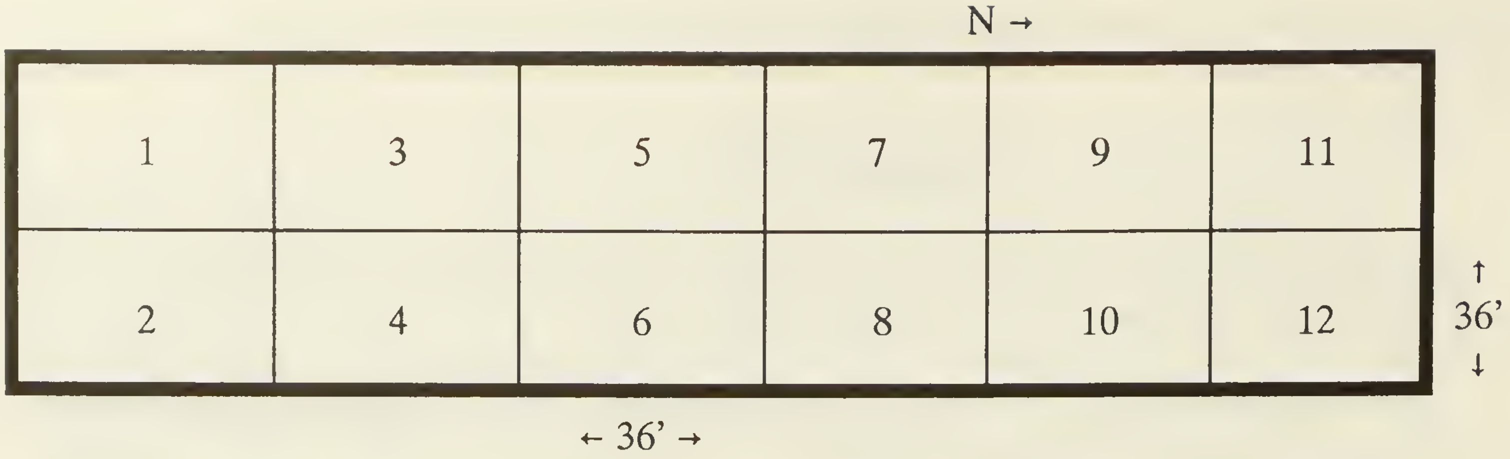
- with and without a 6 inch scoria diffusion barrier;
- with 0, 1 and 2 feet of overburden; and
- with and without 6 inches of topsoil.

These treatments are schematically represented in Figure 1. Because of the difficulty and expense of plot establishment, the treatments and replications were not randomly distributed. The materials underlying and composing treatments and replications are uniform, however, and the arrangement of both treatments and replications is believed to meet the requirements for statistical analysis.

The scoria diffusion barrier, overburden and topsoil, were laid down in October 1990. Seeding at 15.5 lbs/a (Table 1) and fertilization (100 lbs/a, 2-10-0) took place immediately afterward. Topsoiled plots were not fertilized since research has shown that topsoiled minesoils do not respond favorably when fertilized (Rennick et al. 1984). Seed germination and plant establishment were aided by normal or above average spring precipitation in 1991. Determination of plant cover on each plot took place during August 1991 and 1992.

RESULTS

Plant cover was measured in 1991 and 1992. Plant production was measured only in 1992. Summaries of these data are displayed in Tables 2 to 5. Plant cover and production on plots 9, 10, 11, and 12 was so poor that these plots will



Treatments 1, 3, 5, 7, 9 and 11 - diffusion barrier
2, 4, 6, 8, 10 and 12 - no diffusion barrier
11 and 12 - no soil
9 and 10 - 6 inches topsoil
7 and 8 - 1 foot overburden
5 and 6 - 1 foot overburden and 6 inches topsoil
3 and 4 - 2 feet overburden
1 and 2 - 2 feet overburden and 6 inches topsoil

Figure 1. Plot layout.

Table 1. Seed mix for ash disposal pond revegetation study.

Genus Species	**Common Name**
Stipa viridula	Green needlegrass
Agropyron smithii	Western wheatgrass
Agropyron trachycaulum	Slender wheatgrass
Agropyron dasystachyum	Thickspike wheatgrass
Oryzopis hymenoides	Indian ricegrass
Melilotus officinalis	Yellow sweetclover

not be included in the discussion of plant cover or production, except to provide an example of treatments that were unsuccessful. Some plant production was found on all other treatments. It is the explanation of the results of these other treatments that is important.

Plant Cover

The cover of the annual forbs (*Salsola kali* and *Kochia scoparium*) reached maximum levels in 1991 (Table 2). This growth pattern is typical of first growing season plant cover in southeastern Montana. Perennial grass cover never exceeded 33% during this year. However, seeded grass cover increased during the second growing season (1992) as the cover of the annual forbs decreased (Tables 2 and 3). At the time of sampling in 1992 cool season perennial grasses dominated treatments 1, 2, 3, 4, 5, and 6. Yellow sweetclover (*Melilotus officinalis*) dominated plots 7 and 8. The disappearance of the annual forbs and the increase of perennial, seeded grasses is typical of plant cover during the second growing season in this region.

Although yellow sweetclover was seeded on all of the plots, it did not occur on plots 1, 2, 5, or 6, and was present in very small amounts on plot 4. It was very abundant only on plots 7 and 8. Plots 1, 2, 5, and 6 were topsoiled. The vigorous growth of the cool season perennial grasses on these plots may have prevented the development of sweetclover. Sites 7 and 8 were covered with only one foot of overburden and no coversoil. The low cover of perennial grasses and the dominance of sweetclover on these treatments is an indication of the tolerance of the clover for salt and boron and the lack of tolerance for these soil chemical factors in the grasses.

In 1992 topsoiled sites usually produced more perennial grass cover than nontopsoiled sites (Table 3), even though the overburden sites were fertilized and the topsoiled sites received no fertilizer. The luxuriant growth of yellow sweetclover on sites 7 and 8 confuses the picture of total vegetation cover (Table 4). Although perennial grass cover was low on these plots (Sites 7 and 8), the cover of sweetclover was high enough to generate very high total vegetation cover values. The persistence of the composition of the plant communities on the study sites cannot be determined at this time. The yellow sweetclover dominated community may shift to a grass dominated plant community in the future.

It may be inferred from the perennial grass and total perennial vegetation cover data (Tables 3 and 4) that the amount of topsoil and depth of cover soil were the most important factors in the determination of plant growth during the first two growing seasons. When the ash was covered with scoria, 12 in. of overburden, and 6 in. of topsoil (plot 5) or with a greater depth of overburden (plots 1, 2, 3, and 4) grass cover was equal to or exceeded that found on native range sites in the study area (Munshower et al. 1987).

Table 2. Study site vegetation cover values, August 1991 (%).

Species or Plant Group	Treatment											
	1	2	3	4	5	6	7	8	9	1 0	11	12
Salsola kali	74.3±6.3*	66.6±15.0	85.1±10.3	68.8±13.2	53.0±17.8	53.7±2.2	48.8±24.9	44.7±11.7	38.4±13.8	55.2±14.2	40.8±11.9	26.7±6.4
Kochia scoparium	14.3±5.8	25.1±8.7	6.0±5.2	10.9±9.4	28.5±23.9	30.2±2.2	13.1±14.2	1.2±1.8	16.4±6.3	9.3±7.5	6.8±8.0	0.1±0.2
Perennial grasses	26.1±4.5	17.6±9.7	23.3±2.9	33.3±10.8	25.5±7.1	21.2±3.0	18.0±4.0	13.3±4.3	5.4±1.6	6.4±2.5	3.4±2.2	0.6±0.5
Melilotus officinalis	3.4±2.2	5.8±5.8	3.8±1.9	4.1±2.6	2.2±3.3	2.4±3.2	14.1±1.2	0.5±0.4	4.8±4.6	1.9±0.9	6.8±8.0	0.6±1.0
Annual grasses	0.9±1.0	1.6±2.1	1.7±0.9	1.5±1.9	0.9±1.0	0.2±0.4	1.4±0.5	0.1±0.2	0.1±0.2	0.0	0.0	0.0
Other Annual Plants	7.7±7.8	3.9±3.8	1.2±1.8	0.1±0.3	1.2±2.1	2.7±2.3	0.0	0.0	0.5±0.4	0.0	0.0	0.0
Bareground	4.8±2.0	1.4±1.3	0.9±1.0	5.2±4.5	8.0±4.9	6.9±1.3	16.0±6.2	38.9±11.4	39.4±11.2	29.2±7.1	48.3±6.7	71.0±5.7

* N = 2.

Table 3. Study site vegetation cover values, August 1992 (%).

Species or Plant Group	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
Forbs	0.0*	0.0	0.0	0.0	0.0	1.9±2.68	0.0	0.0	0.0	1.7±2.89	12.2±2.41	17.5±6.74
Perennial grasses	76.6±2.89 a	77.5±5.46 a	56.4±5.55 b	56.7±15.9 b	76.7±2.21 a	45.3±12.14 cd	44.4±4.59 cd	37.8±13.47 cd	38.6±6.36 cd	46.1±13.7 5 bc	32.8±8.91 d	3.1±0.48 e
Melilotus officinalis	0.0	0.0	15.6±4.59	1.7±2.89	0.0	0.0	37.2±11.34	37.8±14.25	11.1±10.49	17.5±11.02	4.4±4.59	0.0
Annual grasses	0.6±0.48	4.4±5.55	5.0±6.61	2.5±2.20	0.6±0.96	0.0	0.0	0.8±0.83	0.3±0.48	0.6±0.48	0.0	1.9±0.48
Bareground	14.7±3.76	10.6±0.48	15.8±8.21	15.0±0.0	20.0±4.33	22.5±7.50	17.2±9.14	30.3±0.48	18.3±7.50	26.7±7.22	38.1±18.28	75.0±8.21

* N = 3

Numbers in row followed by the same letter are not significantly different ($p \leq 0.10$).

Table 4. Summarized plant cover data (%).

1991 **Plant Groups**	**Treatment** **1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Annual Forbs	96.3	95.6	93.2	79.8	82.7	86.6	61.9	44.9	55.3	64.5	47.6	26.8
Seeded Species	29.5	23.4	27.1	37.4	27.7	23.6	32.1	19.8	10.2	8.3	3.5	1.2
Total Cover*	126.7	120.6	121.1	118.6	111.4	110.4	95.4	64.8	65.1	72.8	51.1	28.0

1992 **Plant Groups**	**Treatment** **1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Annual Forbs	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	1.7	12.2	17.5
Seeded Species	77.5	82.2	77.5	61.1	77.5	49.4	81.7	76.4	50.0	65.8	52.5	17.8
Total Cover	77.5	82.2	77.5	61.1	77.5	51.3	81.7	76.4	50.0	67.5	64.7	35.3

* Total cover may exceed 100%.

Table 5. Study site production data, August 1992 (lb/a).

Plant Group	**Treatment** **1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Perennial Grasses*	2540 a	2620 a	1500 bc	1780 b	1900 b	1560 bc	880 d	690 d	1160 cd	1120 cd	70 e	5 e
Forbs** (mostly yellow sweetclover)	0 c	0 c	140 c	50 c	0 c	0 c	1940 a	1020 b	50 c	220 c	180 c	0 c

* LSD = 540

** LSD = 380

Numbers in a row followed by different letters are significantly different ($p \leq 0.10$).

The presence of 6 in. of coversoil over 2 ft. of overburden (plots 1 and 2) significantly increased the cover of the cool season perennial grasses. Sites 1, 2, and 5, were the treatments producing the greatest amount of grass cover and all were topsoiled. Site 6 was also topsoiled but produced significantly less grass cover than the other topsoiled sites. This treatment did not have the benefit of the diffusion barrier (as did Site 5) and had only 12 in. of overburden under the coversoil.

Treatments 7 and 8 had 12 in. of overburden over the ash or scoria diffusion barrier but not topsoil covering. These treatments supported significantly less grass cover than treatments 1 through 5 but more yellow sweetclover cover than any other plot (Table 3).

The presence or absence of the diffusion barrier has shown little effect on plant performance in these first two growing seasons. Only plot 6 shows the effect of the diffusion barrier. Plant cover on this plot was significantly less than that measured on plot 5.

Plant Production

Vegetation production data reflect the results of the analysis of plant cover. Plots 1 through 6 produced perennial grasses at rates comparable to or greater than native range sites (Munshower et al. 1987). The topsoiled sites with two feet of overburden (plots 1 and 2) produced the greatest amount of grass biomass (Table 5). Plots 3, 4, 5, and 6 produced significantly less biomass than plots 1 and 2. On plot 7, the heavy growth of yellow sweetclover combined with perennial grass biomass yielded a total vegetation production greater than that on plots 1 and 2 (2820 lb/a). Plot 8 was similar to plots 3 and 4 with 1710 lb/a total production. The increased production of yellow sweetclover on plot 7 may be influenced by the presence of the ash diffusion barrier on this site.

SALT MIGRATION

Analyses of soil pH and EC (electrical conductivity) are shown in Table 6. Data from 1991 and 1992 do not indicate that salt has migrated from the ash into the overlying soil cover. The permanence of this soil pH and EC regime is not known at this time however. Future measurement of these parameters will indicate if the diffusion barrier is working.

SUMMARY AND CONCLUSIONS

Two growing seasons are not sufficient to determine what depth of overburden and/or coversoil are necessary to guarantee permanent vegetation on the ash pond. The success or failure of the diffusion barrier is not clear at this time.

Table 6. Electrical conductivity (dS/m^2) and pH of ash coverings.

	Soil	November 1991*		August 1992**	
Plot	**Depth (in.)**	**pH**	**EC**	**pH**	**EC**
1	0-8	7.7	1.0	7.5	0.7
	8-14	7.7	0.8	7.7	0.7
	16-25	7.6	0.9	7.2	1.1
	25-36	--	--	7.2	2.9
	46-72 (ash)	7.7	6.2	--	--
2	0-8	7.3	2.8	7.5	0.9
	10-20	7.5	1.9	7.3	1.0
	20-26	7.5	0.8	6.9	1.5
	30-50 (ash)	7.7	4.7	7.5	6.9
3	0-8	7.5	1.1	7.5	0.5
	10-18	7.6	0.6	7.4	0.5
	18-24	---	---	7.4	1.2
	24-30	---	---	7.2	3.8
	45-60 (ash)	7.7	5.8	7.6	7.7
5	0-4	7.6	1.5	7.5	0.7
	4-10	7.7	0.6	7.6	0.7
	10-14	7.7	0.7	7.5	1.9
	24-60 (ash)	7.5	7.7	--	--
6	0-8	7.4	1.9	7.3	1.0
	10-18	6.8	3.7	7.4	3.2
	24-50 (ash)	7.5	5.9	7.7	10.7
7	0-8	7.7	0.6	7.8	0.6
	14-20	---	---	7.6	1.2
	22-38 (ash)	7.6	7.0	7.8	6.7
9	0-6	7.1	3.3	7.5	0.7
	6-28 (ash)	7.7	14.3	7.8	4.9
11	0-6	6.5	4.0	7.8	0.6
	8-20 (ash)	7.5	15.0	7.7	6.3

* N = 1

** N = 3

It is apparent that over 12 in. of overburden as a soil covering (plots 7 and 8) is necessary to develop a competitive cool season grass cover in two growing seasons. The increase in cover and production on topsoiled treatments (plots 1, 2, 5, and 6) support the use of this material over the subsoil placed on the ash or diffusion barrier. A topsoil thickness less than the 6 in. depth used in this study may be adequate and should be evaluated.

Plot 5 (6 in. of topsoil over 12 in. overburden) had as much perennial grass cover as Plots 1 and 2 but significantly less production of this plant category. If the diffusion barrier is effective this soil depth and combination may support a grassland plant community. Clearly 24 in. of overburden and 6 in. of topsoil (plots 1 and 2) produced an adequate stand of vegetation. The vegetation growing on plots 3 and 4 is comparable to native grassland cover and production. The future development of this community is important because it will indicate what may be anticipated on reclaimed sites when topsoil is not available. These plots (1, 2, 3, 4, and 5) should be closely monitored during the next two years to record successional changes in plant community structure and soil salt levels.

This study should not be considered complete. The changes in plant communities on the plots should be monitored. Plant community composition, cover, and production, as well as salt movement should be observed for several years. If salt does not migrate into the soil covering and if plant roots penetrate into the ash zone a reclamation plan for the entire ash disposal complex can be developed that is based upon plots 1, 2, 3, 4, and 5. Future monitoring will determine which example will meet revegetation requirements for the disposal ponds.

The development of the plant communities on 1 and 5 will strongly influence the design of the permanent cap on the pond. It may be appropriate to develop a plan for a large demonstration of reclamation on the pond. This demonstration will necessitate location of overburden and a diffusion barrier material. The appropriate size of the diffusion barrier particles must be calculated and the thickness of the overburden soil cover determined.

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EFFECTS OF RECLAMATION TECHNIQUE ON STAND MATURATION IN WESTERN NORTH DAKOTA

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ABSTRACT

Live basal cover (LBC) and production data were collected from nineteen site types within a 216 ha sands and thin sands reclamation area in 1987 and 1991. All site types were seeded between the spring of 1981 and the fall of 1983. Site types were designated due to differing establishment practices which included seeding date, early spring (May) or late spring (June) and mulch source, native hay and/or slough hay. The variables analyzed within site types were alpha diversity, total species, species with 3% or greater relative LBC, and relative production and cover of warm and cool season graminoids. Changes in vegetation structure over time, based on seeding date and/or mulch type, was analyzed using a paired comparison t-test. Within years, a t-test was utilized to compare mulch source and seeding dates. For alpha diversity, multiresponse permutation procedure (MRPP) was used to determine differences. No difference ($P>.05$) in alpha diversity was found within or between years based on mulch type and/or seeding date. Where differences for cool and/or warm season cover or production occurred, a pattern developed within and between years. Over time, the relative cool season component decreased while the warm season component increased. Within years, the late spring seeding dates had a lower relative cool season and a higher warm season component when compared to early spring seeding dates. The sites with native hay mulch had relatively less cool season cover as the stands matured. Seeding date and mulch type appeared to have a significant influence on the initial vegetation composition of a reclaimed grassland. However, post-establishment maturation of stands appeared to reduce differences in vegetation characteristics among the reclamation techniques studied.

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INTRODUCTION

Surface-mining for coal deposits creates areas with major ecological and environmental disturbances. Since the inception of the federal Surface Mining Control and Reclamation Act (SMCRA) in 1977, companies must reclaim lands surface-mined for coal. West of the Mississippi, revegetation success is determined by sampling during the final two years of a ten year responsibility period. In these two years, production, cover, diversity and seasonal variety on reclaimed grasslands are compared to reference areas or approved standards. While it is generally known that these developing plant communities are transitional, this is not adequately considered in the current regulations. The last two consecutive years may be sufficient for total production and cover, but inadequate for addressing positive or negative trends in species diversity and seasonal variety. Changes in young diverse native grassland stands are expected since they are responsive to various establishment and management techniques as well as environmental conditions.

Practices that influence initial stand diversity of seasonal variety characteristics include: seedbed preparation, mulching, mulch type and time of seeding. Additionally, seed quality and seed mix composition will affect initial stand success. Also, establishing a diverse and seasonally balanced stand will depend on favorable environmental conditions.

Following soil redistribution, mulches provide soil stabilization for mined sites (Jones et al. 1969, Meyer et al. 1970). Additionally, a mulch will protect young seedlings from wind and water erosion and maintain surface soil water for a longer period of time for germination and seedling establishment. This is important in the arid and semiarid west, especially if the seeding date is in late spring or early summer. Currently, straw and hay mulches are most commonly used in the Northern Great Plains. Native hay mulches can provide seed sources not available commercially. Thus, native hay mulches provide a potential to increase diversity and create a plant community with a greater capability of self-perpetuation. The role native mulch has regarding a successful stand is relative to the quality of the mulch source. It is important to obtain mulch from an area where soils and vegetation are similar to the reclamation tract. Nilson et al. (1985) determined that native hay mulch provided about 20 percent of the seed source and thus could provide a cost savings during seeding.

Time of seeding and the seed mixture are critical to establishing a seasonally balanced grassland. This balance often hinges on the presence of warm season grasses. Warm season grasses generally do not compete well with cool season species when planted during traditional spring and fall seedings (Williamson 1981, Young 1982). Warm season grasses are not as productive as cool season grasses, but can withstand increased grazing pressure and may provide stability through higher diversity (Ries 1982).

Williamson (1984) found that later seedings (June) had better warm season grass establishment. He pointed out that a seed plan should be in excess of 70 percent perennial warm season grasses due to cool season grass competitiveness. This criteria has been employed the past 14 years on the Glenharold Mine with consistent results.

Little is known concerning secondary succession of young native grassland stands containing multiple species with both cool and warm season growth characteristics. Diversity and seasonal variety are dynamic in responding to management and environmental influences. This study was conducted to evaluate vegetation maturation trends in response to date of seeding and mulch type on a reconstructed sands range site.

STUDY AREA

The study area was located within Section 15 at the Glenharold Mine in western North Dakota. The semiarid, continental climate is characterized by cold winters and hot summers. Average annual precipitation is 44 cm, of which 80 percent falls between April and September. The frost-free growing season averages 120 days.

Coal reserves are located in a landform known as the "Missouri Breaks". Native prairie of the area is dominated by mixed grasses of the wheatgrass-stipa-grama association. Principle soils include mollisols and entisols underlain by sodic montmorillonitic clays, which are typical in spoil materials. Major range sites are shallow, silty, sandy and thin claypan.

Premine soils of the study area were not typical of the mine area and consisted mainly of the Lihen and Krem soil series. These soils made up approximately 80 percent of the disturbance area and contributed 94 percent of the postmine topsoil by volume. Both soil series are loamy fine sands, sands range site, with the Lihen classified as an Entic Haploboroll and the Krem as a Typic Argiboroll. Silty, thin upland and thin sands were found on the remaining area amounting to 8.3%, 6.9% and 4.5%, respectively.

Following topsoil removai, glacial till was located that had clay and sandy clay textures and selectively stripped to a depth of 8 m. All soils were stockpiled for a period of three to five years. Respreading the loamy fine sands topsoil (approximately 30 cm) over the sandy clay subsoil created a soil profile which slowed downward water movement when compared to the premine condition. The result was a more productive soil profile due to more mesic conditions.

MATERIALS AND METHODS

The study area was delineated into 19 vegetation site types (Table 1). Vegetation differences among the sites were due primarily to seeding date, early (May) or late (June) spring, and type of mulch used, native and/or slough hay. Other factors included whether the subsoil was stripped and if the areas were broadcast or drill seeded.

All sites seeded in 1981 were seeded with the same seed mixture (Table 2). In 1982, alfalfa (Medicago sativa) was seeded instead of sweetclover (Melilotus officinalis) at approximately the same rate. Because of its aggressiveness, intermediate wheatgrass (Agropyron intermedium) was replaced by slender wheatgrass (Agropyron caninum) on areas seeded in 1983.

The seed mix and seeding rate took into consideration a ratio of warm and cool season species to establish a seasonally balanced grassland. Williamson (1984) pointed out the importance of using a warm:cool ratio of 3:1 or greater. The ratio used in this mix was 4.7:1, which included 1317 pure live seeds (PLS)/m^2 of warm season species and 282 PLS/m^2 of cool season species.

Haying was utilized on a regular basis on all sites, except site P, for two reasons. First, haying prevented excessive litter buildup. Secondly, timely haying would deplete carbohydrate reserves of intermediate wheatgrass to direct species compostion and improve seasonal balance.

All sites were sampled in 1987 and 1991 for bond release purposes. Production data were collected at community peak standing crop using a 0.25 m^2 frame. Twenty frames per site were clipped by species. Live basal cover (LBC) measurements were obtained using the 10-point frame method described by Cook and Bonham (1977). At each site, 2000 points were read and recorded

Table 1. Establishment characteristics of 19 site types on the Glenharold Mine, Stanton, ND.

Site	Date Seeded	Seeding Operation	Mulch Type	Disturbance Type
A[a]	05/27/82	PD[b]	NH	MD[d]
B	05/18/81	PD	SH	MD
C	05/22/82	PD	NH+SH[c]	MD
D	05/11/82	PD	NH+SH	MD
I	05/10/81	PD	NH+SH	MD
I	05/31/83	PD	SH	MD
I	06/07/83	BS	SH	MD
H	06/05/82	PD	NH	MD
I	06/10/81	PD	NH+SH	MD
J	05/21/82	PD	NH	MD
L	06/09/83	PD	NH	AS
N	05/22/82	PD	NH	MD
O	06/05/82	PD	NH	MD
P	05/23/82	PD	SH	MD
O	06/01/83	BS	SH	MD
P	06/01/83	BS	SH	AS
S	10/10/83	PD	SH	MD
T	06/03/83	PD	SH	MD
V	06/02/82	PD	NH+SH	AS

[a] Note: Sites K and U were merged with sites L and V, respectively, because of having similar vegetative characteristics. Site M is a tamegrass hayland and, therefore, was excluded.

[b] PD = Press drill, BS = Broadcast seeded.

[c] NH = Native hay, SH = Slough hay.

[d] MD = Mine disturbance, AS = Associated disturbance

Table 2. Species and seeding rate for the Section 15 reclamation area.

Species	Scientific Name[a]	Plant Type[b]	Kg/ha PLS[c]	PLS/m^2
Western wheatgrass	Agropyron smithii	CN	5.6	151
Intermediate wheatgrass	Agropyron intermedium	CI	2.2	43
Big bluestem	Andropogon gerardii	WN	1.1	41
Sand bluestem	Andropogon hallii	WN	1.1	28
Little bluestem	Schizachyrium scoparium	WN	2.2	127
Sideoats grama	Bouteloua curtipendula	WN	2.2	95
Blue grama	Bouteloua gracilis	WN	1.1	202
Prairie sandreed	Calamovilfa longifolia	WN	1.1	74
Switchgrass	Panicum virgatum	WN	1.1	96
Sand dropseed	Sporobolus cryptandrus	WN	0.6	654
Green needlegrass	Stipa viridula	CN	2.2	88
Sweetclover	Melilotus officinalis	F	1.1	64
TOTAL			21.6	1663

[a] Scientific names follow the Great Plains Flora Association (1986) or more recent taxonomic considerations.

[b] CN= Cool season native, CI= Cool season introduced,
WN= Warm season native, F= Forb (legume).

[c] PLS= Pure live seed.

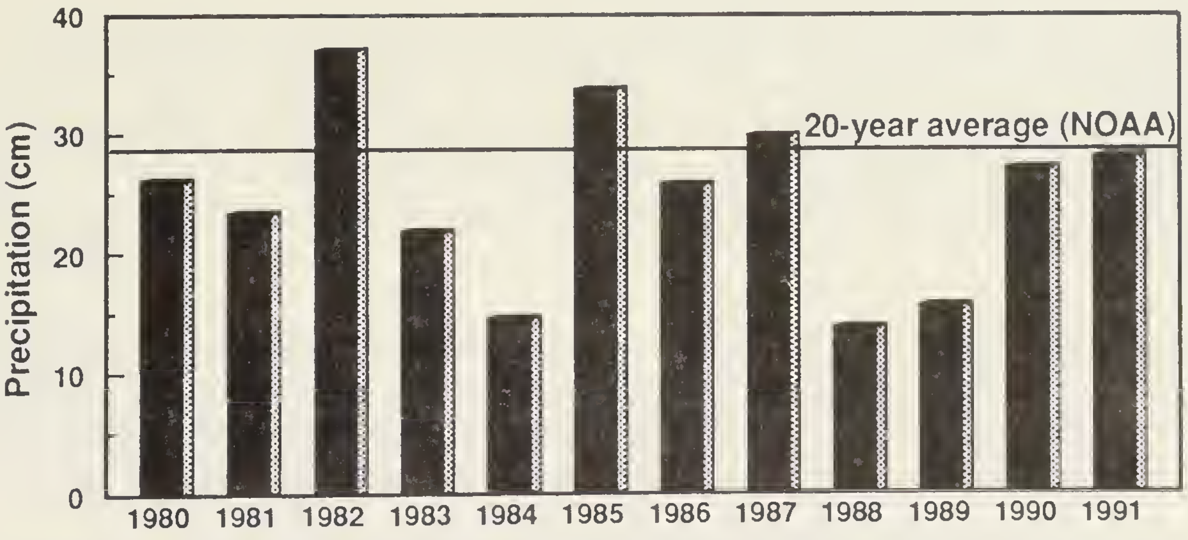

Figure 1. Growing season precipitation from 1980 through 1991 and the 20-year average (NOAA 1987) for the study sites.

by species. Where species richness is discussed, sedges, forbs and shrubs were each considered as one species.

Alpha diversity was calculated using the Shannon-Wiener index (Shannon and Weaver 1973). Multi-response permutation procedure (MRPP), as described by Biondini et al. (1988), was used to determine if alpha diversity differed within/between years for seeding dates and/or mulch type. Vegetation structure over time, based on seeding and/or mulch type, was analyzed with a paired comparison t-test (SAS 1990). Within years, a t-test (SAS 1990) was utilized to compare mulch source and seeding dates.

RESULTS

Precipitation data was recorded for May through September between 1980 and 1991 (Fig. 1). Throughout most of the years the site types developed, precipitation was below the 20-year average (NOAA 1987).

Vegetative characteristics of the 19 site types, in 1987 and 1991, are shown in Table 3. Total species and species having at least 3 percent relative LBC increased over time for each mulch type with one exception. Plant species with 3% LBC or greater decreased under the slough hay mulch treatment. When analyzed by seeding date, the late seeding date showed a decline in the number of species having 3% or greater LBC.

Mulch type and/or seeding date showed no difference ($P>.05$) for alpha diversity (H') within or between years. Although H' increased on 14 sites from 1987 to 1991, this trend was not statistically significant due to variability.

Among mulch treatments, cool season cover, in 1991, was significantly less using native hay compared to slough hay mulch. The interactive effect of mulch type and seeding date, over time, was variable. Early seeding, using the native hay mulch, significantly decreased cool season cover. No interactive effects were found for the slough hay mulch. However, the native and slough hay mulch combination exhibited numerous effects. For the early seeding dates, cool season production and cover decreased ($P<.05$) over time. Cool season production and cover increased significantly ($P<.05$) between 1987 and 1991 for the late seeding dates.

In 1987, warm and cool season production and cover were influenced by the date of seeding. The early seeding dates had greater ($P<.05$) cool season and less warm season production and cover when compared to late seeding dates. However, when seeding dates were compared in 1991, no differences ($P>.05$) in production or cover were evident. Between 1987 and 1991, no difference ($P>.05$) in production and cover were found for the late seedings. However, for early seeding dates, cool season cover decreased ($P<.05$) over time while warm season grass cover increased.

Trends in cool:warm season cover and production are shown in Figures 2 and 3, respectively. Only six sites increased in cool:warm LBC between 1987 and 1991. Each of these sites were late seeding dates. No relationship to mulch type was found among these sites. Fifteen site types were within a cool:warm season LBC ratio of 2:1 or less (Figure 2 shaded area).

The cool:warm ratio based production increased on eight site types (Figure 3). All but two of these sites were seeded in late spring. The two early sites were seeded during the latter part of the early plantings. Again, no cool:warm relationship of production based on mulch type was

Table 3. Vegetative characteristics of 19 reclaimed site types, in 1987 and 1991, on the Glenharold Mine, Stanton, ND.

	Total Species Detected Total		Total Species Detected 3% LBC[a]		H'[b]		Ratio Cool:Warm LBC		Ratio Cool:Warm Production	
	87	91	87	91	87	91	87	91	87	91
A	12	14	4	8	.60	.90	1.6	0.7	5.0	2.6
B	13	13	8	9	.92	1.32	1.6	0.9	7.8	3.9
C	11	14	7	6	.70	.93	1.7	0.8	4.0	2.8
D	15	13	10	8	1.09	.98	1.8	0.5	3.8	1.5
E	13	15	9	7	1.20	.71	5.6	2.3	16.4	3.2
I	12	14	8	8	1.13	.75	1.5	1.1	3.2	1.5
C	12	12	8	8	.94	1.03	0.9	0.5	2.1	1.1
H	13	12	4	7	.95	.70	0.2	0.4	0.9	2.1
I	13	12	8	9	.87	.97	0.7	1.4	2.3	9.4
J	14	16	7	8	.95	.96	2.7	1.0	3.9	5.4
L	11	14	8	6	.60	.53	0.9	0.6	1.1	1.7
N	13	12	10	6	1.16	.94	1.2	0.6	6.6	6.6
D	14	13	8	8	1.16	1.28	0.7	0.8	2.0	1.7
P	13	15	8	10	.72	.76	2.6	0.7	2.1	8.8
D	10	10	10	6	.39	.71	1.9	2.5	9.0	4.6
R	12	16	8	7	.76	.40	0.7	0.7	0.9	2.4
V	10	15	4	7	.40	.76	1.6	1.2	23.1	3.3
A	13	13	13	8	.43	.73	1.6	1.1	1.4	3.2
V	14	14	9	7	.96	.83	0.5	0.7	1.7	52.6
MEAN	13	13	8	8	.86	.88	1.6	1.0	5.1	6.3
MIN	10	10	4	6	.39	.53	0.2	0.4	0.9	1.1
MAX	17	16	13	10	1.20	1.32	5.6	2.5	23.1	52.6

[a] Total number of species detected at 3 percent or more live basal cover.

[b] H' = Shannon-Wiener Plant Species Diversity Index.

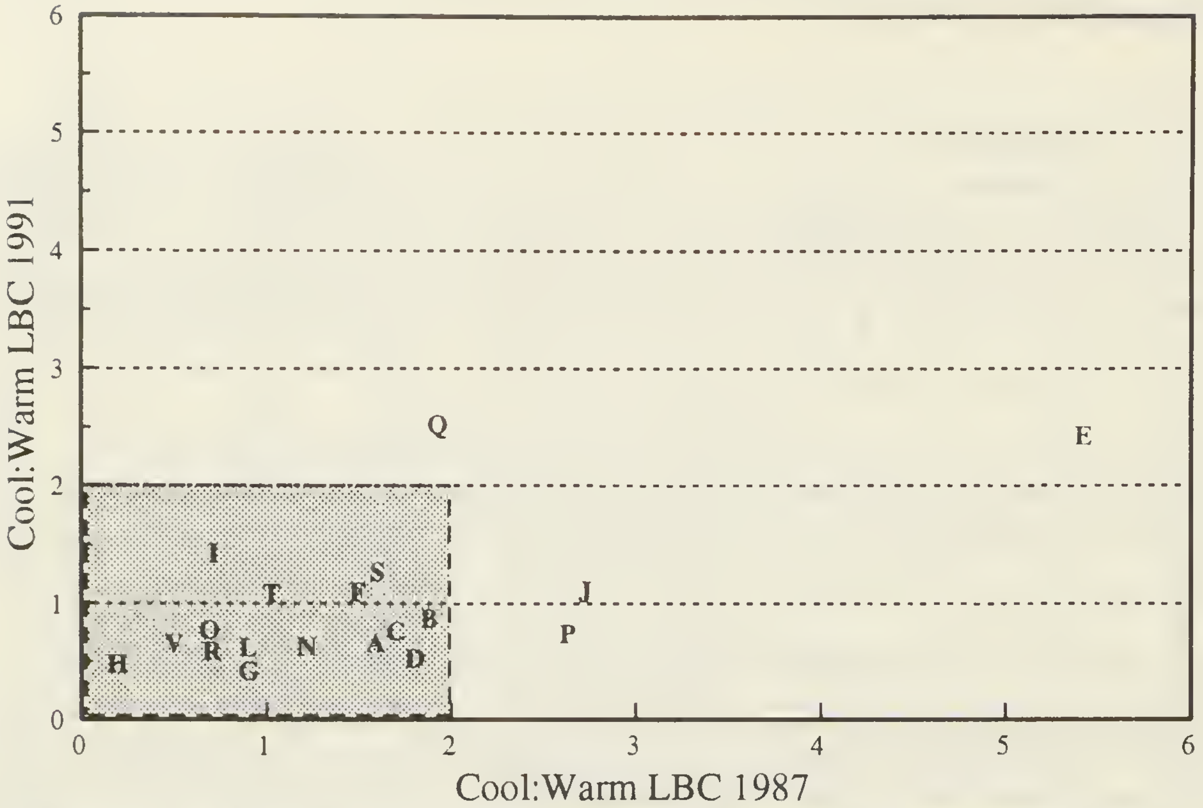

Figure 2. Ratio of cool to warm season grass LBC on 19 site types between 1987 and 1991.

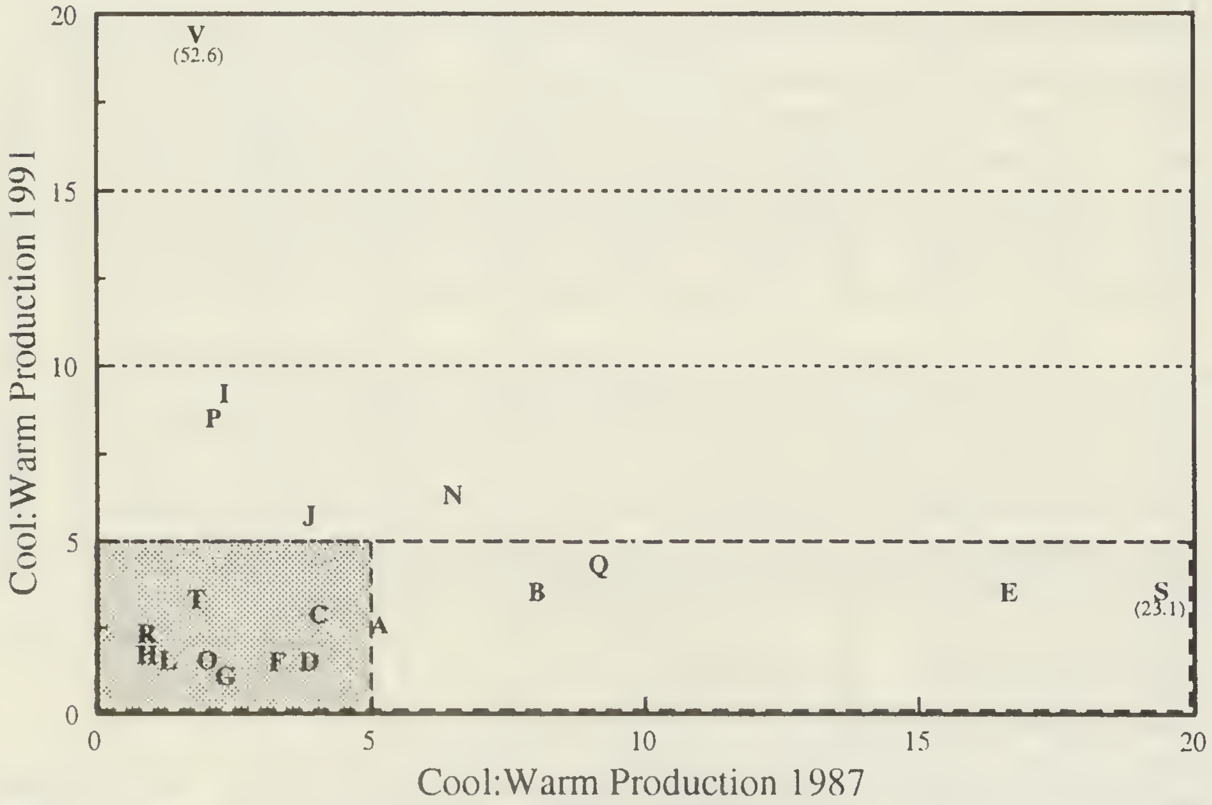

Figure 3. Ratio of cool to warm season grass production on 19 site types between 1987 and 1991.

found among the sites. By 1991, fourteen site types had cool:warm season production ratios of 5:1 or less (Figure 3 shaded areas) which is typical of sandy and sands range sites (USDA, SCS 1975).

DISCUSSION

Traditionally, seeding operations occur as environmental conditions allow. In the past, early spring and fall seeding dates have been recommended as the best times for achieving native grassland reclamation success. Also, earlier native grass mixtures containing both cool and warm season species had a higher cool:warm ratio and often included aggressive introduced species. These practices favor the cool season component and adversely affect the contribution from warm season species. Consequently, meeting the requirements of SMCRA under these conditions will be difficult.

Williamson (1984) suggested later seeding dates to establish seasonally balanced grasslands. Our results support a later seeding date and confirm the importance of developing a seed plan and seeding operation that accounts for the competitive relationships among species. The seed plan for this reclamation area heavily favored the warm season component. In 1991, relative warm season production and LBC comprised 24 and 48 percent, respectively, of the stand composition after 9 to 11 growing seasons. Since the mix included intermediate wheatgrass, annual management operations included haying during the time of flowering and seed head production in order to reduce its affect on overall diversity and seasonal balance. Consequently, production of cool season introduced species including intermediate wheatgrass, smooth brome and Poa species significantly declined ($P<.01$) between 1987 and 1991. During the same period, cool season native species production significantly increased ($P<.01$), resulting in total production being statistically equivalent ($P>.10$) between samplings. Similarly, relative cover values of cool season introduced species decreased from 27 to 19 percent.

Statistical analyses of stand characteristics in 1987 and 1991 showed little to no relationship with mulch type. However, the species composition of the native hay mulch, combined with an August haying date, favored the collection of seed from warm season species that also were seeded. Consequently, its contribution to area diversity was indistinct. Species occurring in the hay and detected on the native hay mulched areas included needle-and-thread (Stipa comata) and prairie junegrass (Koeleria pyramidata), as well as sedges (Carex spp.). Because of the late haying date, the presence of these cool season species was surprising. Sedges inproved considerably in cover and production between 1987 and 1991 and were detected on all sites in 1991. Relative LBC increased from less than one percent in 1987 to four percent in 1991. Similarly, sedge production increased from 13 kg/ha in 1987 to 70 kg/ha in 1991. Additionally, many native forbs are present on these sites which clearly identified the site types where the native hay mulch was used.

In our study, reclamation practices were successful in establishing a diverse initial stand. However, as these stands matured they trended toward a more even seasonal balance regardless of the composition during the first few years. Although the number of species and alpha diversity did not change statistically between 1987 and 1991, H' increased on 14 sites indicating a more even distribution of individuals among species. Additionally, the ratio of cool:warm species, based on LBC, improved or remained the same on 14 sites with the mean ratio decreasing from 1.57 in 1987 to .97 in 1991. These changes represent positive trends in a maturing native grassland stand.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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REVEGETATION METHODS AND SUCCESSES AT THE BLACK THUNDER MINE, CAMPBELL COUNTY, WYOMING

Robert L. Moore[1]

ABSTRACT

Modified Truax native seed drills are used to plant 19-21 species of grasses, forbs and shrubs at the Black Thunder Mine. With a goal of enhancing species diversity and shrub establishment on reclaimed lands, a series of changes in seed mixes and seeding methods have been made over the past 12 years based on evaluation of interim revegetation monitoring data. Alternatives to conventional mulching practices have also been successfully used. Companion crops of annual grain planted along with perennial revegetation species have enhanced the quality of vegetation establishment and proven to be very cost effective in Black Thunder's semiarid climate. Grazing demonstrations (utilizing yearling steers) in conjunction with ongoing wildlife monitoring have documented that Black Thunder's reclaimed lands can sustain grazing pressure 2.4 times that of premined lands, and in summary support the same land uses that existed prior to mining.

Additional Key Words: Revegetation, Seed Drill, Species Diversity, Shrub Establishment, Semiarid Climate, Companion Crops, Land Uses

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INTRODUCTION

Fifteen years have passed since the enactment of the Surface Mining Control and Reclamation Act (SMCRA) and the subsequent passage of commensurate state laws regulating surface mining and reclamation. In Wyoming, many were skeptical as to whether surface-mined lands could be successfully revegetated in a semiarid climate, where frequent droughts have encouraged more than a few farmers and ranchers to seek another line of work.

The ongoing reclamation of Wyoming's coal mines has challenged the revegetation specialist to develop cost-effective methods of establishing stable self-perpetuating rangeland vegetation capable of supporting the same land uses (support of domestic livestock and wildlife) that existed prior to mining. Since 1977, great strides have been made in the development of cost-effective revegetation technology. Thousands of acres have been successfully reclaimed at Wyoming's surface coal mines utilizing various revegetation methods.

It is the intent of this publication to help further the science of restoration ecology by presenting a summary of the revegetation methods and successes at the Black Thunder Mine, the largest surface coal mine in the western hemisphere.

STUDY AREA DESCRIPTION

The Black Thunder Mine, operated by Thunder Basin Coal Company, is located approximately 55 miles south of Gillette, Campbell County, Wyoming. Elevation of the mine ranges from 4700 to 4800 feet, and the climate is semiarid and continental. Annual precipitation averages 12 inches, most of which occurs as rain from April through July. Premining vegetation is characterized by a mosaic of native rangeland plant communities, containing elements of both shortgrass and northern mixed prairie plant associations (Fisser et al, 1975). Specific plant communities are variously co-dominated by cool-season perennial grasses [e.g. western wheatgrass, (*Pascopyrum smithii*) and needle-and-thread grass, (*Stipa comata*)], warm-season perennial grasses [e.g. blue grama, (*Bouteloua gracilis*)] and shrubs [e.g. Wyoming big sagebrush, (*Artemisia tridentata ssp. wyomingensis*)]. The primary pre-mining uses of area rangelands involve grazing by cattle and sheep, and support of wildlife (most conspicuously pronghorn antelope and mule deer).

REVEGETATION METHODS

Tillage

The revegetation process is initiated once the reclaimed surface has been constructed and topsoil replaced to an average depth of 24 inches. The typical seeding seasons are from March 1 - June 1 and October 1 -

December 1 of each year. In the initial step of the revegetation process, topsoil is tilled to a depth of 12-18 inches with a drawn 22½ foot John Deere 1610 flex-wing chisel plow. This primary tillage implement is very efficient at breaking up soil that has been compacted during replacement activities. In topsoil that is extremely dry and compacted, the wings can be folded to their transport positions on top of the center section, and just the center section (14 feet) used for tillage. The wings add extra weight to the center section allowing it to penetrate the compacted soil.

The next step is final seedbed preparation. This is accomplished with a drawn 22 foot Farmhand flex-wing Ultra Mulcher 43 (roller harrow), with 19 inch heavy duty rollers and front and rear looped C-Tines. This secondary tillage implement breaks up the clods left from primary tillage operations and firms up the final seedbed.

Seeding

A model 12 Truax Native Seed Drill is used to seed 19-21 species of cool and warm season grasses, forbs and shrubs (Table 1). The seed drill has been modified to optimize the seeding of various seed types at appropriate seeding depths. The seed drill modifications along with adjustments to seeding rates have been made in a series of changes over several years, based on periodic evaluation of interim vegetation monitoring data with the goal of enhancing species diversity and shrub establishment.

Seed drill modifications include pulling the tubes from the small seed box out of the drill opener assemblies to allow broadcasting of small seed types; replacing the accordion tubes used to transmit fluffy seed types to the drill opener assemblies with long, straight tubes which broadcast the seed above the ground between the openers (to distribute the seed more evenly); attaching a 4 foot by 8 foot removable drag built from an English tine harrow to the back of the drill to cover broadcast seed; and removing the press wheels on the drill opener assemblies to allow the drag to move the seed around and diminish some of the "row" effect from the seed drill. These modifications result in essentially all species, except for the four different wheatgrasses, green needlegrass (Stipa viridula) and sainfoin (Onobrychis viciaefolia) (Table 1), being broadcast seeded by the drill and being covered by the drag. Fine shrub seed, such as big sagebrush and rubber rabbitbrush (Chrysothamnus nauseosus) are broadcast seeded from the drill on a second pass made perpendicular to the first pass, if practicable, with the drag removed.

Mulching/Companion Crops

When seeding was completed, the standard operation for many years was to blow mulch on top of the seeded area at approximately two tons/acre and then crimp the straw into the soil to secure it. The main purpose of this practice was to control erosion prior to plant establishment and to help retain soil moisture. To avoid contamination from weed seeds

TABLE 1

Permanent Upland Seed Mixture

Scientific Name	Common Name		Pounds Pure Live Seed Per Acre
*Pascopyrum smithii (Rosanna)	Western wheatgrass		1.5
*Elymus lanceolatus (Critana)	Thickspike wheatgrass		1.5
*Elymus lanceolatus (Sodar)	Thickspike wheatgrass		1.5
*Elymus trachycaulus (Pryor)	Slender wheatgrass		1.0
*Stipa viridula (Lodorm)	Green needlegrass		3.0
Oryzopsis hymenoides (Nezpar)	Indian ricegrass		3.5
Calamovilfa longifolia (Goshen)	Prairie sandreed		4.0
Bouteloua gracilis	Blue grama		2.0
Sporobolus cryptandrus	Sand dropseed		2.0
Sporobolus airoides	Alkali sacaton		2.0
Bouteloua curtipendula (Pierre)	Sideoats grama		3.5
Schizachyrium scoparium (Camper)	Little bluestem		2.0
Medicago sativa (Ladak)	Alfalfa		.7
Onobrychis viciaefolia (Eski)	Common Sainfoin		2.0
Astragalus cicer (Monarch)	Cicer milkvetch		1.0
Ratibida columnaris	Upright prairie coneflower		.7
Artemisia tridentata (Wyomingensis)	Big sagebrush	(5)	-
Chrysothamnus nauseosus	Rubber rabbitbrush	(5)	-
Atriplex canescens	Fourwing saltbush	(1)	.5
Atriplex gardneri	Gardner saltbush	(1)	.5
Ceratoides lanata	Common Winterfat	(1)	.5
		(44.9)	33.4

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* Comprises the base mix used for all permanent and semipermanent seed mixes. 8-10 PLS lbs./ac of annual grain is added as a companion crop.

( ) Rates for permanent upland shrubland/grass sites.

contained in the mulch, grass straw was originally used from certified fields previously inspected by the County Weed and Pest for designated weeds, noxious species and pests. A primary concern became the durability, availability and cost of grass straw. A switch was then made to using barley or winter wheat straw from certified fields. This source of mulch was substantially less expensive and proved to be more durable than the grass straw.

But there were still major concerns associated with the practice of mulching such as finding application times when wind conditions were appropriate, the cost of mulch and mulch application, and the difficulty of achieving a uniform application. There had to be a better mousetrap!

Attention then focused on revegetated topsoil stockpiles (semipermanent reclamation). The practice for several years had been to mulch only the areas susceptible to rill and gully erosion (slopes), and not mulch the top portions of the stockpiles. The 5 Pure Live Seed (PLS) lbs./ac of annual grain included in the seed mix had worked well in stabilizing the top portions of stockpiles until the perennial grasses were established.

The decision was then made to increase the seeding rate of the annual grain used as a companion crop from 5 to 10 PLS lbs./ac in the permanent seed mix. Areas susceptible to rill and gully erosion would still be mulched at two tons/acre. The companion crops would be mowed prior to maturity in early July to prevent reseeding and subsequent competition. The mowed material would provide a thin layer of mulch on top of the perennial seedlings for protection and also help retain soil moisture.

The use of companion crops in lieu of mulching on permanent reclamation was initiated in 1988 at the Black Thunder Mine, and to date has yielded very positive results. Utilization of companion crops has resulted in the establishment of successful vegetation with a cost savings of 53% (Black Thunder Mine 1992 Annual Report) versus mulching at two tons/acre. Permanent reclamation that is susceptible to rill and gully erosion (e.g. slopes) is still mulched. Observations from 1988-1992 indicate that companion crops are more successful when planted in the spring. Fall plantings are susceptible to wind erosion when dry soil conditions limit freezing of surface soils.

No Fertilization or Irrigation

Results from studies (Stoecker-Keammerer and Assoc. 1986) conducted at Black Thunder's sister mine (Coal Creek), 26 miles to the north, indicated that fertilization and irrigation are not necessary for revegetation success. In fact, observations indicated fertilizers mainly benefitted annual forbs during the first growing season; and that the more successful approach was to allow these species to establish under natural conditions over time.

MONITORING

Vegetation

Interim vegetation monitoring data have been collected periodically at the Black Thunder Mine over the last 10 years. The purpose of the monitoring was to evaluate the results of various revegetation methods and to document vegetation trends. The vegetation data collection program consists of obtaining information about productivity, species composition, shrub density and vegetation canopy cover.

For the purpose of comparing vegetation data from reclaimed lands at the Black Thunder Mine to vegetation data collected from native lands immediately adjacent to Black Thunder, Table 2 has been created. This table is a comparison of vegetation data collected on reclaimed areas seeded in 1988, 1989 and 1990 at Black Thunder Mine (Stoecker-Keammerer and Assoc. 1991) and baseline vegetation data collected the same year on the West Black Thunder Coal Lease Tract (Stoecker-Keammerer and Assoc. 1991) immediately adjacent to Black Thunder. It is interesting to note that reclaimed areas PR-S88-1 and PR-F88-1 were seeded in 1988, during one of the worst droughts in the last 10 years.

Wildlife

Wyoming is noted for its wildlife populations. Consequently, wildlife use is one of the designated postmining land uses. Wildlife studies have been conducted at the Black Thunder Mine since operations were initiated. Over the years a wildlife monitoring program was developed that includes annual surveys for big game animals, raptors, waterfowl, sage grouse and migratory birds of high federal interest. Passerine surveys and small mammal trapping were added to the monitoring program in recent years.

Wildlife monitoring conducted from 1983-1992 (Postovit 1992) has documented use of Black thunder's reclaimed lands by raptors, waterfowl, passerines, small mammals and big game.

Livestock Performance

One of the standards of reclamation success is demonstrating the ability of the reclaimed community to sustain grazing pressure at least equal to premining grazing pressure. In 1988, a two pasture rotational grazing demonstration was initiated (Moore, Keammerer and DePuit 1989). Two fenced pastures, one 99 acres in size and the other 84 acres, were constructed on the oldest reclaimed areas at the Black Thunder Mine. The fenced pastures included areas that were reclaimed in 1981, 1982 and 1983. The study design called for livestock (yearling steers) to be placed in one of the pastures the first part of May continuing until around July

TABLE 2

Comparison of 1991 Vegetation Monitoring Data Collected from Black thunder Mine Reclaimed Areas and Vegetation Types on the West Black Thunder Study Area

	Mean Total Vegetation Cover (Percent)	Mean Production (g/m^2)	Mean Species Density Value (# Species/m^2)	Mean Shrub Density (# Shrubs/m^2)
Reclaimed Areas				
PR-S88-1 (grassland)	34.0	183.2	6.4	.2
PR-F88-1 (grassland)	18.0	99.8	10.9	.3
PR-S89-3 (shrubland)	38.5	261.3	6.7	2.9
PR-F89-1 (shrubland)	21.8	112.4	15.6	6.1
PR-S90-1 (shrubland)	26.5	225.7	13.4	12.8
Native Vegetation Types				
Mixed Grass Prairie	28.0	98.4	11.2	.5
Big Sagebrush Shrubland	31.4	55.9	13.6	2.1
Playa Grassland	23.2	110.6	5.1	.02
Streamside Meadow	48.7	232.4	8.4	.03

15th or until a level of approximately 50% utilization of the forage had occurred. If 50% utilization had not been attained by July 15th, the cattle would still be moved to the other pasture, where they would remain until approximately October 1st. After the first of October, the cattle would be removed from the second pasture and sold. The sequence of early and late season use would be alternated between the two pastures among successive years of grazing. No dietary supplements other than salt blocks would be provided.

To date, the pastures have been grazed for five consecutive years (1988-1992) utilizing the previously described study design with 25-30 yearling steers. Forage utilization ranged from 50% to 85% in the pastures. This wide range of utilization is due to unpredictable droughts encountered during the 1988 and 1992 grazing seasons. The average stocking rate for the reclaimed pastures during the past five years was 2.2 ac/animal unit month (AUM). When compared to the average stocking rate of 5.5 ac/AUM on native rangelands adjacent to Black Thunder, the reclaimed pastures sustained grazing pressure 2.4 times that of adjacent native rangeland. Weight gain responses were excellent with the steers averaging 1.89 pounds/animal/day during the five-year period. A summary of livestock weight responses from 1988-1992 is presented in Table 3.

Summary and Conclusions

The revegetation methods developed over the last 12 years at the Black Thunder Mine have demonstrated proven success. Seeding utilizing modified Truax Native Seed Drills have established vegetation on reclaimed lands capable of supporting the same land uses that existed prior to mining. Companion crops of annual grain have been successfully used as an alternative to mulching. Continuing wildlife studies have documented extensive use of reclaimed lands by raptors, passerines, waterfowl, small mammals and big game. Results of 5 years of livestock grazing have shown that reclaimed lands can sustain grazing pressure 2.4 times that of premined lands while supporting excellent livestock weight gains averaging 1.89 pounds/animal/day.

TABLE 3

Comparison of 1988, 1989, 1990, 1991 and 1992
Livestock Weight Responses

Grazing Period/Year/Duration	Beginning Average Weight	Ending Average Weight	Total Gain/ Animal	Average/Gain/ Animal/Day
Entire Season Grazing-1988 (131 Days)	510 lb.	748 lb.	238 lb.	1.82 lb.
Entire Season Grazing-1989 (127 Days)	509 lb.	783 lb.	274 lb.	2.16 lb.
Entire Season Grazing-1990 (165 Days)	663 lb.	955 lb.	292 lb.	1.78 lb.
Entire Season Grazing-1991 (157 Days)	597 lb.	880 lb.	283 lb.	1.80 lb.
Entire Season Grazing-1992 (133 Days)	535 lb.	785 lb.	251 lb.	1.89 lb.

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NONSEEDED SPECIES INVASION OF TWELVE REVEGETATED SURFACE MINED SITES AT COLSTRIP, MT

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ABSTRACT

In 1977 the Surface Mining Control and Reclamation Act (SMCRA) was passed requiring surface mining companies to "establish ...a diverse, effective, and permanent vegetative cover of the same seasonal variety...capable of self regeneration and plant succession at least equal in extent of cover to the natural vegetation of the native area." Nonseeded species play an important role in revegetation by increasing community diversity. Their voluntary encroachment onto revegetated minesoils is desirable to the mining industry since final bond release depends upon reclamation success.

The objectives of this study were to identify factors significantly affecting nonseeded species invasion of sites seeded with primarily native species and to provide recommendations for promoting the invasion of desirable nonseeded species. To examine the effects of the season of planting on lifeform dominance, six of the sites chosen had been seeded in the spring and six had been seeded in the fall.

Analyses indicated that significant variables affecting nonseeded species invasion were the age of the reclaimed sites and the ratio of edge to interior of a field. Seeding mixtures and seeding rates also appeared to influence the number of invading species on these sites. Other variables analyzed were: topsoil depth, total soil depth, size of the field, season of planting, and distance from undisturbed, windward seed sources.

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INTRODUCTION

The requirement to reestablish diversity within the ten year bonding period is the most challenging aspect of revegetation on western mined lands today. Reclamation managers must make decisions which can positively influence the outcome of revegetation efforts and which are cost effective. Some cultural aspects of reclamation such as seeding mixtures, seeding rates, methods, and mulching practices can influence revegetation costs and success. These factors can be manipulated by the reclamation specialist to enhance diversity, thereby improving the probability of obtaining final bond release.

Another factor to consider during the reclamation process is the shape of the revegetated area. The shape could be manipulated to increase the amount of edge of the patch by undulating the borders. This mimics natural landscapes and therefore is aesthetically more appealing, it also may positively influence the occurrence of invading species.

METHODS AND MATERIALS

Twelve revegetated surface mined sites at Western Energy's Rosebud mine in southeast Montana were chosen for this study on the basis of age and available historical data. These data included seed mixes, methods, rates, soil depths, and time of planting. The twelve sites were divided into six pairs of spring and fall seeding dates and were either directly adjacent to one another or within the same mine area. Ages of the fields ranged from two to eleven years. Samples were collected twice in 1991, in late May, to estimate the cover of early forbs and again in late July to measure standing biomass by lifeform as well as percent cover of the dominant species.

Acreage ranged from 1.6 ha (4 a) to 11.3 ha (28 a). To limit bias, each field was visually divided into fourths and a stake was set at a central point for each quarter. Each sample location was placed at a randomly selected distance and direction from the central stake.

Percent canopy cover was measured using Daubenmire (1959) coverage classes. Cover data were collected by placing twenty frames (20 x 50 cm) in each field, five within each quarter, and recording areal cover in each frame by species. The number of sample frames was based on species area curves. To be consistent and to provide 'replication', the number of frames per field was held constant at twenty. In late July canopy cover as well as standing biomass were measured. For species encountered both times, the record with the greatest amount of cover was entered into the data base.

Vegetation was clipped to approximately 1 cm from the ground to estimate standing biomass by lifeform. Vegetative litter was also collected. After estimating cover, a 50 X 50 cm frame was laid on top of the left edge of the cover frame. The plants were clipped by lifeform, put into appropriately marked paper sacks, and oven dried for forty-eight hours at 56° C and then weighed.

Seeding mixtures were known for each field. Each species encountered in a frame was entered into the data base as either seeded or nonseeded to determine invading species.

Distances from undisturbed sites were taken from maps provided by Western Energy Company. Two directions were measured for the prevailing wind. The dominant wind usually rises from the northwest but as summer approaches it becomes more southeasterly (Mitchell and Super 1972).

The ratio of edge to interior of a field was calculated from Western Energy maps. The field's circumference, or edge, was measured and divided by the area within each field giving a ratio of the edge to interior (m/ha).

Topsoil and subsoil samples were collected for each site by WECO and shipped to Montana State University. Samples were analyzed at the Reclamation Research laboratory for pH, EC, and for textural class using methods described in Methods of Soil Analysis (Gee and Bauder 1986)

RESULTS AND DISCUSSION

Analyses consisted of covariance analysis using the General Linear Model (GLM) procedure in SAS (Version 6.03, SAS Institute, Cary, NC, 1983). Variables were considered significant when P-values were 0.10 or lower. Dependent variables were percent areal cover, productivity of standing biomass, and number of invading species. Independent variables were age of fields, season of planting, ratio of edge to interior of fields, soil depths, and distance from undisturbed windward sites from the northwest and southeast. Seeding methods, mixes, and rates were not included in models for analysis of variance; each field was uniquely defined by a combination of these variables which are discussed in the text.

Analyses indicated that significant variables affecting nonseeded species invasion were the age of the reclaimed sites and the ratio of edge to interior of a field. Seeding mixtures and seeding rates also appeared to influence the number of invading species on these sites.

Productivity

Production of standing biomass was not significantly affected by any of the independent variables. The fall seeded fields had slightly greater productivity averaging 2250 kg/ha versus 2164 kg/ha for the spring seeded fields. This may be due to the increased production of cool, introduced, annual grasses on the fall seeded sites. (See below, Season of Planting). A summary of production by lifeform is listed in Table 1.

Production on unmined native range land in Colstrip, Montana averaged 1000 kg/ha (Munshower and Neuman 1983). Productivity of reclaimed surface mined lands was double that of native range land in the Colstrip area after two years (Sindelar 1980). This rate of productivity was attributed to introduced grasses and legumes selected for forage production.

Results from the present study also showed productivity to be nearly double the rate of productivity for native range even though they were seeded primarily with native species. These results concur with DePuit et al. (1980) who

Table 1. Production by lifeform (kg/ha).

FIELD	AGE	CNP*	CIP*	CIA*	WNP*	FORB	LITTER	TOTAL*
4884	2	1898	101	85	1	432	1649	2533
4881	3	1846	17	104	0	550	1438	2532
4862	4	1116	436	84	56	366	1667	2058
4852	5	1327	296	39	15	638	1056	2325
4861	5	594	37	13	0	1036	1436	1679
1851	6	1486	28	151	34	46	1893	1745
3852	6	1330	408	593	1	247	1803	2579
3841	7	1991	43	71	17	436	1603	2645
2832	8	1853	58	60	11	570	1949	2552
3821	9	1665	58	48	0	337	1293	2212
4801	10	947	7	232	0	600	2754	1768
3801	10	468	19	493	0	865	1922	1851

* CNP - Cool Season Native Perennial; CIP - Cool Season Introduced Perennial; CIA - Cool Season Introducted Annual; WNP - Warm Season Native Perennial; TOTAL - productivity of all grasses and forbs.

indicated that exclusive seeding of native species is not at the expense of productivity.

Percent Cover

Results for this variable were surprising since analyses showed a significant interaction between topsoil depth and season of planting on the dependent variable percent cover. As the amount of topsoil increased, the amount of canopy cover decreased significantly for the spring seedings, but not for the fall seedings. Care should be taken when interpreting these results. Barth (1984) has shown that a coversoil depth of up to 46 cm directly influenced plant growth. All sites in this study exceeded this recommendation and there was little variation in soil depths among sites.

Number of Invading Species

Two of the independent variables analyzed, age and the ratio of edge to interior of a field, influenced the number invading species.

As the age of a field increased, the number of invading species increased. This may be due to the mortality of the initially seeded species, such as *Agropyron trachycaulum*, which opens up the community for the invasion of other species, or it may be a function of community stabilization.

As the ratio of edge to interior of the field increased, the number of invading species also increased. This supports the importance of patch shape in landscapes found by Forman and Godron (1981). The greater the amount of edge, the more diverse are the microhabitats created by the association of patch shape and environmental factors such as wind and sun. Increasing the amount of edge around a field increases the number of microhabitats thereby creating additional niches for species invasion. A summary of invasion for all fields is presented in Table 2.

Season of Planting

Spring seedings from this study averaged 109 kg/ha of cool season, introduced, annual grasses (*Bromus tectorum* and *B. japonicus*) which was less than that of native range at 200 kg/ha (Munshower and Neuman 1983). In contrast, fall seedings were higher than native range in annual grass production with a mean of 220 kg/ha.

Spring seedings appeared to produce more perennial, warm season grasses; production was more than twice that of fall seeded fields. Warm season grass production for spring seedings averaged 19 kg/ha whereas fall seedings averaged

Table 2. Summary of invasion for all fields.

Field	Age	Edge (m/ha)	Planted	Total seeded species	Species within frames	No. of invader species	Richness*
3801	10	377	fall	4 +cover	35	31	14
4801	10	238	spring	4 +cover	19	17	9
1851	6	245	spring	15	28	15	9
3841	7	222	fall	15+cover	31	23	12
3852	6	299	fall	15	20	14	12
4852	5	259	spring	16	25	17	12
4861	5	196	fall	21	24	13	11
4862	4	307	spring	19	26	13	13
4884	4	307	spring	19	26	13	10
4881	3	211	fall	15	33	22	11
2832	8	183	spring	18+cover	26	20	14
3821	9	353	fall	4 +cover	27	25	12

*Based on species with >1% cover.

only 3 kg/ha. However, to attribute this effect only to the time of seeding would not be justifiable. The seed mixes also played an important role. Some fields were seeded with an exclusive 'warm season grass' mix. Other fields were seeded with a 'supplemental' mix which also contained warm season grass species.

Support for the argument that spring seeding increases warm season grass production can be seen in the only pair of fields in this study to be seeded with the exclusive 'warm season' mix. The fall seeding had no warm season grass production while the spring seeding produced 56 kg/ha of warm season grasses. This was the greatest amount recorded for any field in the study. These findings concur with Rennick and Munshower (1985) who also studied the effects of seeding date on the structure of plant community reestablishment. They found perennial warm season grasses did the poorest of all life forms for all seeding dates, however, warm season grasses were found only on the spring seeded plots where their composition was less than one percent. By comparison, the composition of this lifeform on native range is from 2.5 to 5.1 percent.

Seeding Variables

Seeding rates varied for each site ranging from 9 to 77 kg/ha PLS. The rate of seeding does not appear to influence the productivity of standing biomass over time but these findings are inconclusive without replication.

The number of invading species seems to be influenced by the seeding mix. Three fields with a high number of invader species: 3801, 4801, 3821, were seeded with only four species plus a cover crop.

Field 3801 had the greatest number of invading species for all fields in this study. It was one of the three fields previously mentioned that was seeded with an uplands mixture of only four species and a cover crop. All fields with a cover crop had higher numbers of invaders than fields with no cover crop. This supports the idea that leaving a community open during the early stages of succession provides space for invader species to become established. When the annual cover crop dies back it leaves improved soil conditions and open niches in the community for the invasion of nonseeded species. In contrast, the field with the lowest number of invading species, 4861, had the highest number of seeded species and no cover crop.

The seeding rate for field 3801 was also the lowest for any field and it was broadcast seeded. DePuit et al. (1980) found that broadcast seeding at low rates promoted community diversity. However, they noted the advantage of broadcast seeding over drill seeding had disappeared by the third growing season. These fields were nine (3821) and ten years old (3801 and 4801) at the time of this study and were drill and broadcast seeded, respectively. No advantage of broadcast over drill seeding was apparent in these three fields. Without replication of the seeding methods at the same rates, these findings are inconclusive. Nevertheless, they suggest that when seeding only a few species at low rates the number of invading species increases.

The temporary cover crop helps alleviate the problem of invasion by weedy species and improves soil conditions by increasing air and water infiltration. In a shortgrass community in Texas, Fowler (1988) noted that the benefits of improved soil water and temperature conditions from previous plant growth apparently outweighed any negative competitive effects in this dry environment.

Soil Factors

Almost all fields had a loamy-sand texture. Soil pH ranged from mildly alkaline to moderately alkaline. Electrical conductivity was nonsaline for all fields.

CONCLUSIONS

Reclamation practices used today employ traditional agriculture methods developed for the growth of economic crops, not for the recreation of ecosystems. Learning to construct these systems using the tools at hand and within the guidelines set by regulatory agencies, is a challenge for reclamation specialists.

Managers of the restoration process must comply with regulations designed to protect the environment but that also created homogenized soils and landscapes. Therefore, the goals of recreating the diversity of the natural landscape are met with limited success. Based on results from this study, certain factors under the control of the reclamation manager encourage the invasion of nonseeded species and thereby increase diversity.

Seeding mixtures are the most conspicuous and easily controlled factor. Care should be taken not to overcompensate for a lack of understanding of plant community relationships by seeding too many species (Vallentine 1989). Seeding only a few species along with a cover crop encourages invasion. This is in part due to the open niches created when the annual cover crop dies back. It may also be a factor of improved soil structure created by the root system of the cover crop (Schuman et al. 1991). Seeding at lower rates also appears to increase nonseeded species invasion. This is most likely due to reduced interspecific competition among plants.

The season of planting appears to influence warm season grass production; the spring seedings are more productive for this lifeform. Including the exclusive 'warm season' mix and seeding in the spring appears to increase production of this lifeform on minesoils at Colstrip, MT.

Rehabilitated minesites lack the diverse natural microhabitats which were destroyed during the mining process. Increasing the ratio of edge to interior of reclaimed sites may help to increase the number of microhabitats available without adversely affecting reclamation costs. Undulating the edges of fields during final grading of the spoil and topsoil could increase the ratio of edge to interior of fields and thereby increase the number of microsites. This would also be more appealing visually since straight lines are seldom seen in nature.

Some efforts have been made by reclamation specialists to mitigate the problem of landscape homogeneity. Placing boulder piles and tree snags on the revegetated sites creates caches of moisture, provides shade, and creates habitat for fauna and flora which may not otherwise be found there.

Freedom of experimentation, in cooperation with regulators, would allow the creation of a more diverse landscape. Allowances, such as varying topsoil depths or leaving areas without any topsoil but exposed gravel, could provide microsite variations resulting in different plant communities.

The ten year bonding period imposed under SMCRA may not be a sufficient amount of time for the reclaimed plant community to become as diverse as a reference area in the semi-arid West. Reclamation success should be based on utility, not on whether or not identical ecosystem composition as been reached.

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RESTORATION OF BIO-DIVERSITY ON A STRIP MINED AREA IN SOUTH AFRICA

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ABSTRACT

With the decision to strip mine an area of more than 3000 ha south of the Pretoria-Witwatersrand-Vereeniging metropolitan area, a decision was made to convert the area from one dominated by pioneer secondary grasslands, block plantings of exotic trees and a natural wetland, utilized to large extent by exotic game species, to a game park with a diversity of habitats, food resources and game species. To achieve this objective a holistic development program incorporating the planned yet adaptive management of both mined and unmined areas in different phases was adopted. This plan makes provision for the restoration of land capability where : a proportion of arable areas are used for woodland; grassland areas be restored with greater diversity and a higher proportion of desirable species and wetland areas include sites varying from bottomland marshes to seasonal mudflats and open water. In the implementation of this program the regular auditing of the condition of soil, vegetation, water and wildlife will form the basis of an adaptive management policy. The development of this facility on the doorstep of a metropolitan area offers opportunities for ecological education, research and recreation.

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INTRODUCTION

Mining companies in South Africa have accepted in principle the need for comprehensive environmental impact studies and the development of rehabilitation plans based on the restoration of land capability. The planned land use on such rehabilitated areas will, however, vary dependent on topographical, edaphic and climatological limitations as well as economic considerations. In the final analysis the land use systems implemented must be both ecologically and economically stable to ensure sustainability. By their very nature neither economy or ecology are static and land use systems must, therefore, be flexible. Such flexibility implies that changes in a land use system or management variable may be implemented in reaction to results obtained with current practice. On many mines land use systems are based on livestock, agronomy and even forestry, the emphasis being on land use in harmony with resources (land capability) and economy. This paper reports on the use of rehabilitated land for wildlife which requires a wide diversity of food resources and habitats. Apart from the greater stability theoretically afforded by such diversity, this option offers opportunities for ecological education, research and recreation for the large metropolitan population located within a radius of 100 km.

PRESENT LAND USE

The area to be mined covers an area of more than 3000 ha adjacent to the Vaal river. Located at an altitude of 1425-1445 m a.s.l. approximately 80% of the area has a grassland (not suited for annual cultivation) capability; 15% may be regarded as wetlands (dominated by marshy conditions rather than open water) and 5% has an arable potential. The latter class is situated along the river bank and, although a small proportion is affected by levee construction, it will remain largely unaffected by the strip-mining operation. The main limitation on land use on the gently sloping topography is the low fertility, poor moisture holding capacity and highly erodible nature of the aeolian sands of two meters overlying 16m of alluvial deposits.

The area receives an average annual rainfall of 650mm, with 82% concentrated in the summer growing season (October-March). With an annual evaporation rate of three times the precipitation, combined with the poor moisture status of most soils, drought conditions often place limits on adapted species and plant productivity. While the hottest months (December and January) have a mean maximum temperature of 27°C, mean minimum temperatures in the coldest month (July) of are below zero and extremes of 38°C and -11°C respectively have been recorded.

Since underground mining first commenced on the property in 1884, most of the area was used for forestry and cropping purposes. As a result of the unfavourable conditions, however, neither cropping or forestry proved to be economically or ecologically stable. With the commencement of strip mining in 1984, approximately

40% of the area to be mined was established to block plantings of oak *(Quercus robusta)* and saligna *(Eucalyptus* spp) with subsidiary amounts of black locust *(Robinia pseudoacacia)*, *Pinus* spp, cypress *(Cupressus sempervirens)*, ash *(Fraxinus* spp), pin oak *(Q. palustris)*, honey locust *(Gleditsia triancanthos)* and weeping willow *(Salix babylonica)*. The plantations of oak (originally planted to simulate European conditions and to supply feed for fallow deer introduced into a private park), although nearly 100 years old, were characterized by great variability in height and diameter and gave a very unthrifty appearance. Apart from the marshy wetland areas where some relics of climax grassland, typified by species such as *Themeda triandra, Cymbopogon pluronodus, Setaria flabellata* and *Hyparrhenia hirta*, still persisted the remainder of the area to be mined (45%) is characterized by secondary grasslands dominated by pioneer species such as *Eragrostis curvula, E. plana, Cynodon dactylon, Trichoneura grandiglumis, Aristida congesta, A. diffusa, Pogonarthria squarrosa, Asparagus* spp and *Stoebe vulgaris*. The basal cover on these secondary grasslands is generally very poor - less than 6% compared with 15-20% on grassland in a good condition.

This vegetation was used primarily by game animals for many years which were characterized by the high proportion of : fallow deer (39%, based on animal units), eland (22%) and blesbuck (15%). Remaining species included zebra (5%), wildebeest (5%), gemsbuck (4%), hartebeest (4%), kudu (3%) and other species (3%). Other species included small numbers of springbuck, impala, duiker, steenbuck, ostrich, hares, porcupine, mongoose and jackal. Amongst the game birds recorded yellowbill duck, redbill teal, spurwing geese, helmeted guineafowl and Swainson's francolin made up the greatest numbers although in excess of 80 other species have been spotted on the property. The most notable feature of this system of utilization was the relatively low grazing capacity of the grassland component, which is illustrated by the relatively low stocking rate of grazing animals (33% of total animal units) and the poor condition of the grassland. In comparison, browsers made up 64% of the animal units and subsisted mainly on the exotic oak species. The development of clearly defined browse lines in the oak plantations and the paucity of material under these trees are indicative of overutilization by the browsers.

PROPOSED LAND USE

In a mining operation planned to extend over four decades the final land use will only be realized in the distant future. Rehabilitation and management plans are, however, concerned with the present and as such must retain flexibility with adaptive responses being based on constant monitoring of soil, vegetation, water and animal components of the ecosystem. The three major areas requiring consideration are

: non-mining areas
: future mining areas
: mined areas

Non-mining areas

These areas, comprising only 300 ha, will be utilized by a balance of browsers and grazers. The balance will be determined primarily by the availability and condition of the respective forage resources. In the case of the *WOODY COMPONENT* the Eucalyptus spp only be retained, or planted, where they may serve a screening function. Block plantings of this genera will be cleared, with the possible exception of occasional good specimens (20-30/ha) to create an open woodland, and these areas oversown with a grassland mixture. The browse value of the oak must, however, be recognized and as many good specimens as possible will be retained. A thinning program should, however, be initiated to remove stunted and diseased trees, thereby : reducing competition for the limited soil moisture and improving the growth of the remaining trees; reducing the impact of straight lines and blocks (The creation of new roadways along the contour and avoidance of the old "block-road-network" would further reduce this effect); creating diversity in terms of open meadows, open woodland and relatively dense thickets within the oak plantation. In the short term such selective thinning may increase the availability of browse by stimulating coppicing and will divert browsing animals from the newly planted berry, seed and thicket species such as *Pyrocantha, Cotoneaster, Lespedeza, Buddleia, Grewia* and *Rhus*, which are recommended for strategic spots to improve habitat and food diversity for a greater range of small mammals and bird life. In the initial phase (8-10 years) such plantings would require special protection from large herbivores and would, therefore, be limited to a small number of locations.

The ***herbaceous layer*** is currently in a poor condition! Where this herbaceous layer is a component of woodland areas inputs will be required to identify forbs and grasses adapted to such conditions. Where, however, the herbaceous layer is the major component, as in open grassland, management inputs in terms of : manipulating the number and type of grazing animals; the judicious use of fire and the introduction of a greater diversity of grass and legume species will have as objectives an improved botanical composition (in terms of diversity, palatability and stability) and basal cover. This may only be achieved by taking positive steps to overseed or sodseed desired species to provide locii from which such introduced species may spread.

Future mining areas

As mining progresses the game fences will be moved and *the area designated for future mining together with non-mining areas* will become gradually smaller. Of the mixture of browsers and grazers using these areas it is proposed to start transferring some of the smaller grazers to rehabilitated areas within five years (as soon as viable management units of 300-400 ha are available). Browsers, however, will only be transferred to rehabilitated areas once trees are well grown out (3-5m). Where it is a clearly defined objective to improve the condition of both grassland and woody components on non-mining areas (previous section) the objectives on future mining areas will be to provide adequate forage of a good quality for a range of game animals without causing soil erosion. This may be achieved by : manipulating the numbers of different types of animals; encouraging coppice growth for browsing animals and by burning of the secondary grasslands. Where such future mining areas are used together with non-mining areas - where the objective is improvement - such management manipulations may be used to reduce the pressure on the latter areas.

Mined areas

The rehabilitation program envisaged makes provision for 75% grassland, 15% woodland and 10% wetland. The immediate implication is that as the rehabilitated areas increase relative to the unmined areas so too will the proportion of grazers. This would more nearly approximate the original vegetation *(Cymbopogon-Themeda* veld) described by Acocks (1988) and the wildlife that used the area originally.

Rehabilitation practices for grassland

After regrading of the spoil these areas should be "topsoiled" with a soft overburden consisting of alluvial deposits. By using this approach the "advantages" of the improved moisture holding characteristics of the higher clay content of the alluvial layer should be incorporated into the growing medium for the restored grassland. After ripping, to alleviate the compaction caused by heavy machinery, this substrate will be limed and fertilized to ensure, at the least, adequate levels of pH, P and K in the growing medium. The area will then be seeded with a mixture of grasses and forbs adapted to such soil and climatic conditions. A favourable micro-climate for the emerging seedlings will be created by mulching the area with old hay.

The current seeding mixture includes *Chloris gayana* (a weak perennial), *Eragrostis tef* (an annual nurse crop), *Digitaria eriantha* (a popular grazing and hay crop in the area) and *Anthephora pubescens* (an indigenous species which is well adapted to sandy soils). In addition there is often considerable volunteer *Eragrostis curvula, E. lehmanniana* and *Cynodon dactylon*. A balanced N-P-K fertilization program - based on local calibration studies conducted on rehabilitated grassland - will be maintained until the pasture is three to four years old, or for as long as hay is harvested from the pasture. At this stage suitable adapted legumes have not been identified for inclusion into the seeding mixture but serious consideration is currently being given to *Lespedeza cuneata* and *Coranilla varia* for this purpose. The successful inclusion of such species would alter the balance of nutrients in the fertilization program. In the longer term such grass pastures will be grazed by game, once a large enough area is available, and the level of fertilization will be reduced and ultimately (after 10-15 years) terminated. Increased species diversity will be further encouraged by overseeding with locally adapted species. Such seed will be obtained by harvesting hay from rangeland in a good condition (e.g. on the headlands of cultivated fields and along roadways) and spreading it over the pasture, or from a specific program to collect and propogate indigenous species with desirable characteristics.

Rehabilitation practices for woodland

In contrast to the existing block plantings of trees future plantings will simulate the natural occurrence of woodland along drainage lines, adjacent to open water and on rocky crests and ridges. Being confined to only 15% of the rehabilitated area a special effort will be made to improve conditions for the trees. Inputs will include : a higher clay content than the aeolian sands; cross ripping as deep as possible to improve rooting depth; the incorporation of manure and water absorbent polymers to improve water holding capacity; the provision of a better level of fertility during the establishment phase; provision of water in drought periods; mulching to reduce moisture losses and weed competition; support of saplings and the production and use of healthy seedlings.

In the choice of species and density of planting diversity will be encouraged by using well adapted exotic species such as *Quercus, Populus, Gleditsia, Robinia, Fraxinus, Salix, Pyrocantha* and *Contoneaster* in combination with indigenous species such as *Acacia, Celtis, Combretum, Olea, Rhus, Buddleia* and *Grewia*. These represent both evergreen and deciduous types and with the variety of growth forms, espacements and densities to create open meadows, open woodland (< 100/ha), savannah (200-300/ha) and dense thickets (800-1000/ha), will represent a variety of feed resources and habitats for a wide variety of mammals and birds.

Once planted the management program will make provision for : irrigation and follow-up fertilization to ensure rapid but sound growth; weed control; pruning and thinning; protection against insects and rodents and protection against fire. In addition larger grazing mammals should be excluded from woodland areas for approximately ten years and browsing species until such time as browse species are 3-5 m tall.

Rehabilitation practices for wetlands

The proposed wetlands will be more diverse than the original marshy area located on clay soils with impeded drainage. During the regrading, when provision is made for surface hydrology, a variety of habitats including : drainage line marshes; gentle gradients to create mud flats, shallows and marshes at the edge of the envisaged water table; islands and open water are envisaged. Apart from the variety of water fowl which would be attracted to such areas, as wide a range of aquatic plant and animal life as possible as well as larger mammals usually associated with riverine vegetation will be introduced.

Adaptive management policy

The basis of the proposed management policy for non-mining and mined areas is the description of objectives and targets for both rehabilitation and utilization, the assessment of the degree of success in achieving these objectives and if necessary the *ADAPTATION* of rehabilitation and/or management policies and practice. Such assessments are based on the monitoring of soil, water, vegetation and wildlife on a regular basis. Critical soil parameters would include aspects such as bulk density, permeability, effective rooting depth, moisture status (as influenced by infiltration, drainage, texture and organic matter), soil acidity and nutrient status. Surface conditions such as capping or crusting, plant litter and surface erosion will also be assessed. With respect to water monitoring the water balance (as influenced by surface runoff, evapo-transpiration losses and infiltration) will have a strong influence on the level and quality of ground water in the pit. Changes in the botanical composition, canopy cover, density and basal cover which will be assessed in both grassland and woodland components, will be supplemented by information on the productivity and availability of forage for grazers and browsers in the different strata. As with the vegetation, wildlife audits will record species diversity, numbers and condition.

Management responses involve manipulations of the vegetation by means of such inputs as overseeding, additional planting of woody plants, thinning or burning whereas manipulations of wildlife involve new introductions or culling to alter the stocking rate and/or the proportions of different types of animals depending on the suitability of the environment for specific animals or, conversely, on the influence of certain animals on the environment. Wildlife concentrations or movements might also be manipulated to some degree by the provision and placement of supplemental licks and watering points, although the use of rotational burning of the grassland areas would probably be more effective for this purpose.

In the final analysis the formulation and successful implementation of a holistic rehabilitation and utilization program, whether it be a simplistic livestock production system or a complex ecosystem with great diversity of all components, as in this instance, will depend on regular audits of all resources and the willingness to react to deviations from declared objectives.

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MATCHING SAMPLE SIZE TO OBJECTIVES

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ABSTRACT

As bond release schedules progress, vegetational comparisons are receiving closer scrutiny. Since the variance and differences between means are inherent to vegetational data, the power of conclusions is tied to sample size. Too few samples lead to Type II errors: concluding that significant differences between means don't exist when, in fact, they do. For quantitative data, minimum sample sizes can be computed for specified levels of precision. For five major community types and four levels of precision, minimum sample sizes have been computed based on canopy-coverage and peak standing crop. Minimum numbers of shrub density samples have been calculated for three shrub and one open forest type at four levels of precision. Reference areas usually, but not always, can be adequately sampled with fewer samples than comparable community types in large areas of rangeland. Sample adequacy can also be addressed floristically using graphical techniques, the ambiguities and limitations of which are discussed.

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INTRODUCTION

A common goal of vegetation sampling is to make comparisons, e.g., between reclaimed areas and reference areas or approved standards, and to determine whether inventories are adequate. Based on data collected in southeast Montana, this paper presents some realistic estimates of the required numbers of samples for several common community types, using statistical and graphical approaches.

ACKNOWLEDGMENTS

Thanks to the Spring Creek Coal Co. for permission to use data collected at that mine.

METHODS

Sampling

Data were collected in 1991 at the Spring Creek Coal mine located near the Tongue River Reservoir in Big Horn County, Montana. The long-term average annual precipitation in the area is estimated to be approximately 12 inches (SCS 1980), but the mean at the mine for the 1980-1991 period was 8.3 inches annually, with 3.2 inches falling in the May-June months.

Samples were randomly located in native rangeland and reference areas according to community type. All transects were assigned random azimuths.

Canopy-coverage (Daubenmire 1959) was estimated as accurately as possible; cover classes were not used. In grass and shrub/grass communities, coverage was sampled with a pair of 0.5 x 1 meter subplots located three meters apart. Coverage estimates from both subplots were combined, averaged and counted collectively as one sample. In Ponderosa pine communities, four subplots located at three-meter intervals were sampled and combined. The use of subplots reduces variance in the data and can be more cost-effective than locating additional samples, particularly when sample locations are randomly selected in large study areas.

Peak standing crop (PSC) was measured by harvesting current year's growth in July-August, air-drying to constant weight and weighing. Herbs and shrubs were sampled for peak standing crop, but trees were not.

At every canopy-coverage sampling location, the first 0.5 m^2 plot was clipped after coverage sampling was complete. Harvested materials were sorted according to growth forms. (See Table 3 for examples of growth forms.) Sampling the same plots for coverage and peak standing crop (PSC) allows double sampling, if necessary or desired. In pine-dominated communities, the first and third 0.5 m^2 subplots were harvested, combined and counted as one sample for statistical purposes.

Shrub density was measured in 5 x 15 meter (45 m^2) rectangular plots with the long axis oriented along the cover transect. Shrubs were counted when their basal area was primarily within the plot perimeter. The rule for determining whether a shrub was counted as one or more individuals was this: if additional stems, which might have originated with the core plant, arose from within the canopy of the core plant, all stems were counted as a single plant. If a questionable stem arose from outside the core canopy, it was counted as an additional plant.

Statistics

Parametric statistics apply to quantitative data such as density, canopy-coverage and PSC. The variance and mean calculated from some preliminary sampling, or from sampling in prior years, is used to determine the number of samples necessary to estimate a population mean within a specified confidence interval. The formula follows (Cook and Bonham 1977, Milner and Hughes 1968):

$$n \min = 2 \frac{t^2 \, s^2}{(\text{mean} \times \% \text{ change})^2}$$

where t is the "t" value from a t-distribution table for the appropriate (n-1) degrees of freedom and probability level; s^2 is the variance or standard deviation squared; and "percent change" is the percentage of the population mean to be detected. If more samples are indicated, the calculation is iterated with all data following additional sampling.

Writing for the International Biome Program, Milner and Hughes (1968) recommended that alpha (Type I error) be 0.10. A minimum of 10 samples was suggested in any case.

If the test hypothesis takes the form: communities A and B differ, without respect to whether A is expected to be greater or lesser than B, a two-tailed t-test is appropriate. When a mean is being compared to technical standards, a confidence interval for the mean would be used.

RESULTS

Parametric Techniques

Canopy-Coverage

Table 1 presents some examples of the numbers of samples necessary to meet four levels of precision in native rangeland based on two-tailed t-distributions. Statistical criteria range from an 80% probability of obtaining a sample mean within 20% of the true (population) mean to a 90% probability of obtaining a sample mean within 10% of the true mean. Desired sample sizes were computed for total canopy-coverage and the combined canopy-coverage of the two dominant growth forms. Only the most abundant species or growth forms can be determined with reasonable precision. (Note: All the canopy-coverage data for each individual type were collected by a single observer, which is likely to result in smaller variance, hence fewer samples, than if several investigators provide estimates of canopy-coverage.)

The required number of samples is directly related to the variance of the data. Large sample plots or samples comprised of subplots will necessitate fewer samples. Fewer samples will be needed for narrowly defined homogeneous community types than for broadly defined heterogeneous types. The notion that recognizing fewer vegetation types will necessitate fewer total samples may not hold true when sample adequacy is based on growth forms. Vegetation mapping also plays a role in sample size; detailed mapping results in lower variance, particularly for growth forms.

How much precision is justified? The answer depends on the importance of the information, e.g., whether it will be buried in an appendix or used to evaluate bond release criteria. But if two means are compared, each based on the number of samples necessary to estimate a sample mean within 20% of the true mean at the 80% probability level, there is a high likelihood of making a Type II error. In other words, due to the uncertainty associated with each estimated mean and variance, one is likely to conclude that the means do not differ when, in fact, they do.

Consider an example of why a Type II error is likely when the .8/.2 criterion is used to calculate the necessary number of samples. Two communities are to be compared for total canopy-coverage. Community A has mean canopy-coverage of 120, and a standard deviation of 25. Community B has mean cover of 92, and a standard deviation of 19. Each has been sampled with five plots -- just enough to meet the .8/.2 precision requirement.

Can we say that the coverages of these communities differ at the 80% probability level? The 80% confidence interval for

A is 120 +/- 17. The confidence interval for B is 92 +/- 13.

Table 1. Calculated minimal numbers of canopy-coverage samples based on total coverage and combined coverage of the two dominant growth forms. Data were collected from native rangeland in southeast Montana.

COMMUNITY TYPE/FACTOR	DESIRED PRECISION .8/.2*	.9/.2	.8/.1	.9/.1
*Agsm*** Total CC	2	3	7	11
NCPG + ICAG***	8	14	31	53
Arca/Agsm Total CC	3	5	11	18
ICAG + NCPG	14	24	56	94
Artr/Agsm Total CC	4	7	16	26
NCPG + ICAG	13	21	49	83
NCPG + NWS	5	9	20	33
Artr/Agsp Total CC	6	10	22	37
NCPG + NWS	7	12	27	45
Pipo/Agsp Total CC	18	29	69	114
NCPG + NCT	32	53	125	208

* For example, to obtain a sample mean with an 80% likelihood of being within 20% of the true (population) mean.

** The familiar binomial abbreviations comprised of the first two letters of the genus followed by the first two letter of the specific epithet.

*** The two dominant growth forms for each type. ICAG = Introduced Cool-season Annual Grasses; NCPG = Native Cool-season Perennial Grasses; NWS = Native Warm-season Shrubs; NCT = Native Cool-season Trees.

The confidence intervals overlap, so we must accept the null hypothesis -- no significant difference in canopy-coverage, despite the fact that the sample mean for A is about 30% greater than the mean for B.

Choosing more rigorous confidence limits reduces the likelihood of Type I errors, but cannot overcome the limitations imposed by a small sample size, and increases the chance of a Type II error. Using the same means, standard deviations and sample sizes presented in the preceding paragraph, the 90% confidence limits for A and B are 120 +/- 24 and 92 +/- 18 respectively.

For the above example, if we set alpha at 0.10, the power is about 0.65, and conversely Type II error is 0.35. Power is the probability of detecting a difference if there is a difference. Power cannot be determined unless the difference to be detected is specified. For alpha = 0.10 and power = .85, about nine samples would be needed.

The likelihood of making a Type II error can be reduced (i.e., "power" is increased) when the difference between means is large and/or variance is small, neither of which is usually under the ecologist's control, and by increasing sample size, which changes the t-distribution. If carried to extremes, a very large sample size may result in detection small differences that are statistically significant but have no practical consequences.

Table 2 answers the question, will fewer samples be needed from a restricted area, such as a reference area a few acres in size, than from many communities in a landscape. Not always. Three of the five community types in Table 2 required more samples for total canopy-coverage from reference areas than from 1500 acres of native rangeland. In contrast, four of the five community types required fewer samples for the combined canopy-coverage of the two dominant growth forms in reference areas than in native rangeland. Generalizations are not very enlightening because the homo/heterogeneity of sampled communities exerts controlling influence.

Peak Standing Crop

Since measuring peak standing crop is costly and laborious, excessive sampling is best avoided. Unfortunately, PSC cannot always be reliably estimated at the time of sampling because fresh weights are not always a reliable indicator of dried weights, especially if large succulent forbs comprise part of the samples. Fresh weights of uniformly cured plant matter provide a fairly reliable estimate of dried weights.

More samples are usually needed to achieve the same statistical reliability for peak standing crop than for canopy-coverage in grass and shrub/grass dominated communities. When comparing Table 1 with Table 3, recall that each canopy-coverge sample in grass/shrub types was comprised of two 0.5 m^2 plots, whereas each PSC sample was a single 0.5 m^2 plot. The fact remains that peak standing crop usually requires more samples than coverage, and each PSC sample is more expensive due to the time required for harvesting, transporting, drying and weighing.

Table 2. Calculated minimal numbers of canopy-coverage samples based on total coverage and combined coverage of the two dominant growth forms. Data were collected from coal mine reference areas in southeast Montana.

COMMUNITY TYPE/FACTOR	DESIRED PRECISION .8/.2	.9/.2	.8/.1	.9/.1
Agsm Total CC	2	4	8	14
NCPG + ICAG	5	8	19	32
Arca/Agcr Total CC	3	6	12	21
ICAG + ICPG	6	10	23	39
Artr/Agsm Total CC	2	2	5	8
ICAG + NCPG	2	3	6	10
Artr/Agsp Total CC	8	14	33	55
NCPG + NWS	13	21	49	83
Pipo/Agsp Total CC	9	13	30	51
NCPG + NCT	16	27	64	108

Table 3. Calculated minimal numbers of peak standing crop (PSC) samples based on total PSC and combined PSC of the two dominant growth forms. Data were collected from native rangeland in southeast Montana.

COMMUNITY TYPE/FACTOR	DESIRED PRECISION .8/.2	.9/.2	.8/.1	.9/.1
Agsm Total PSC	10	16	38	64
NCPG + ICAG	16	27	64	108
Arca/Agsm Total PSC	12	20	46	79
NCPG + ICAG	20	33	78	132
Artr/Agsm Total PSC	15	24	57	96
NCPG + ICAG	13	21	50	83
Artr/Agsp Total PSC	16	27	64	108
NCPG + ICAG	18	31	72	121
Pipo/Agsp Total PSC	24	40	96	161
NCPG + NWPF*	34	57	135	226

* Native Warm Perennial Forbs.

Double sampling may save the day if the necessary number of PSC samples was not attained, and further sampling is impractical. Regress canopy-coverage on PSC, either total or by growth forms, and if the regression equations are sufficiently reliable, additional PSC data can be generated from coverage data for unharvested plots. This assumes that each PSC plot was first sampled for coverage, and that there are more coverage samples than PSC samples.

The number of samples necessary for shrub density can be on a par with coverage, or may require additional samples (Table 4). A very high number of samples may be indicated if stems of rhizomatous species (e.g., snowberry), or species with a clumped distribution (e.g., chokecherry or willows), are counted. Typically, such species are absent from many or most samples while abundant in others, which leads to non-normal distributions, in which case the t-distribution does not apply and the formula cited above (see Methods) is inappropriate.

Table 4. Calculated minimal numbers of shrub density samples. Data were collected from native rangeland in southeast Montana.

COMMUNITY	DESIRED PRECISION			
TYPE	.8/.2	.9/.2	.8/.1	.9/.1
Arca/Agsm	27	46	108	181
Artr/Agsm	7	12	28	47
Artr/Agsp	4	7	15	25
Pipo/Agsp	38	64	151	252

Other Quantitative Data

Revegetation standards may also incorporate seasonality, origin and diversity requirements. Seasonality and origin (introduced or native) can be easily addressed without statistics using quantitative data and comparisons by class

Measures of sociability and species diversity such as dominance and equitability are numerical values computed from quantitative data, e.g., cover. Comparisons can be made using a confidence interval approach. The issue of minimum sample size is best addressed directly for the quantitative data used in combination with a relatively complete floral inventory, which is discussed next.

NON-STATISTICAL METHODS

Quantitative Data

The minimum number of samples necessary to accurately characterize a community or community type can be assessed using graphical methods. Unfortunately, graphs of real data rarely take the unambiguous form of examples used in textbooks, and graph interpretation is somewhat subjective, or at least not always conclusive. In most graphical approaches, the goal is to sample until the graph flattens, at which point the cost of additional information (e.g., new species) is outweighed by the cost of additional sampling.

One problem with graphical approaches is that excessive samples must be taken before adequate sampling can be demonstrated. It is also possible to manipulate the order in which samples are tabulated to provide a desired result. One benefit is that a graphical approach can be used for presence/absence data.

For quantitative data, the running mean may be plotted against the number of samples (X-axis). Another alternative is to plot the running mean of the variance, since the objective is to get an accurate estimate of the variance as well as the mean. (See Chapman 1976, pp. 105-6.) Usually it takes more samples to reliably estimate the variance than the mean. However, statistical approaches already discussed are the most satisfactory way to evaluate quantitative data.

The Species-Area Curve

For a variety of reasons, sampling should represent all species as fully as possible. Here a graphical approach finds good application. The total number of species sampled in a community or type is plotted against the number of samples or total area sampled. (See Daubenmire 1968, pp. 89-91, and Mueller-Dombois and Ellenberg 1974, pp. 47-52.) The resulting graph is often called a species-area curve. The "breakpoint" in the graph indicates the "minimal area" or minimum number of plots (of specified size) necessary for adequate floristic completeness. The result is valid only for the vegetation association and sample design used. For example, if 20 systematically spaced 0.1 m^2 plots along several transects proves to be adequate, it does not follow that a single 2 m^2 plot or two 1 m^2 plots will also suffice.

The floristic approach can complement statistical approaches based on quantitative data by promoting a degree of floristic completeness in inventories, and at the same time indicate both species richness and floristic homogeneity. However, one caveat is appropriate: if the community or type is weedy, the graph will not flatten until the weed component is well-inventoried. A detailed weed inventory is not usually worth the effort of extensive sampling.

Figure 1 is a classic species-area curve, with a sharp increase in species for the first samples followed by a much more gradual addition of species. Twenty-six species were sampled in the first nine plots. Seventeen additional plots yielded only five more species. About a dozen plots would have been adequate.

A more ambiguous pattern is depicted in Figure 2. The graph flattens considerably after only six samples, with 22 species sampled to that point. If only 20 samples had been taken (n[species] = 28), one might have concluded that only six were justified. From plot 21 to 26, six new species were encountered, and another three species from plot 26 to plot 32. This phenomenon is not too uncommon when sampling progresses from one end of a study area to the other, and a new condition is encountered, e.g., a different substrate or different land use history.

Although the graph in Figure 2 never becomes as flat as one might wish, a break clearly occurs between plots one and nine, and one might conclude that fewer than 10 samples are needed. However, the investigator should recognize that this community type is more diverse floristically than 10 samples would indicate. The cost of additional samples must be weighed against the risk of controversy later, when additional sampling is impractical. A conservative approach (Cain 1938) for ambiguous species-area curves would be to take enough samples to include 90% of the total species (in this case, 25 samples = 33 species), but this is an *ex post facto* approach.

CONCLUSIONS

Sampling without consideration of the ultimate use of the data can lead to an insufficient sample size, resulting in insufficient power to make satisfactory conclusions. For quantitative data, sample sizes can be estimated for the desired level of precision using some preliminary data. When comparisons are made, power/Type II error is an appropriate statistical focus, but the difference between means must be known. Relative floristic completeness is best addressed by plotting the total number of species sampled vs. number of samples or total area sampled. It may be advisable to base the actual number of samples on a

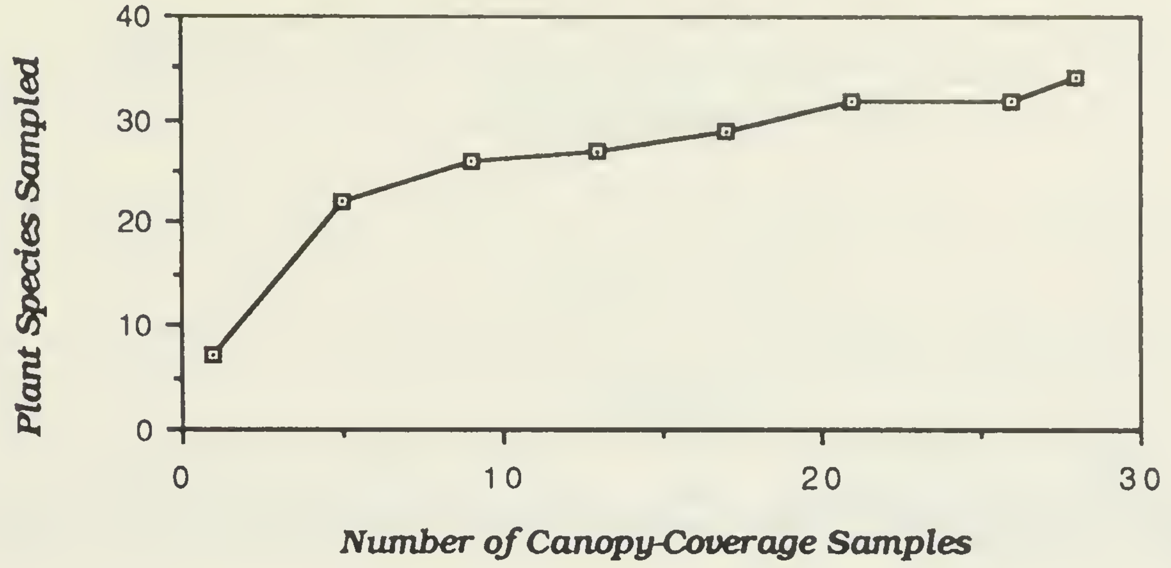

Figure 1 - SPECIES RICHNESS CURVE FOR THE ATSM ARTR/AGSM COMMUNITY TYPE

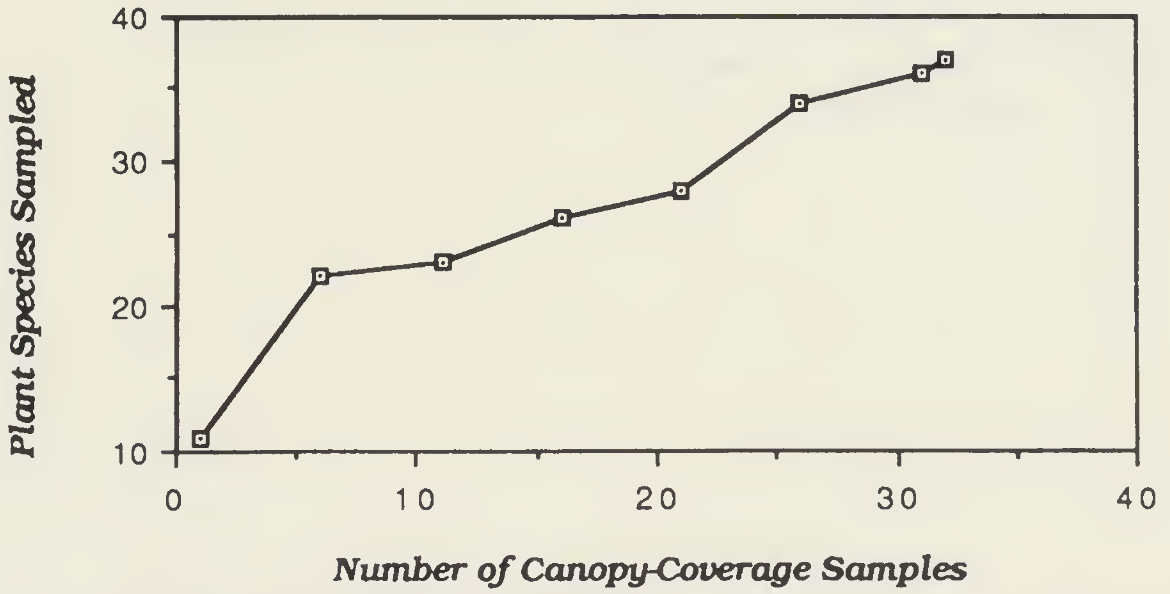

Figure 2 - SPECIES RICHNESS CURVE FOR THE ARTR/AGSP COMMUNITY TYPE

combination of floristic and statistical criteria, not the highest estimate for each criterion.

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METHOD FOR CLASSIFICATION AND MONITORING OF HABITAT TYPES

Daniel W. Uresk[1]

ABSTRACT

A method was developed over a 12 year period and applied to nine habitat types using cluster analyses followed by stepwise discriminant analysis to delineate ecological seral stages on the Northern Great Plains. Classification and monitoring between and within seral stages is 90%+ accurate when only three variables are measured. This method has been applied and implemented on over 200,000 acres of woodlands and grasslands in South Dakota and Nebraska. Costs are approximately $0.45/acre. The methods developed are quantitative, precise, easy, time-efficient, and meet the goals of resource managers with a minimum of bias.

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NATIONAL PARK SERVICE SOIL CONSERVATION SERVICE PLANT MATERIALS PROGRAM

Wendell G. Hassell [1] and William R. Beavers[2]

ABSTRACT

The Soil Conservation Service (SCS) and the National Park Service (NPS) are cooperating in a Plant Materials Program in the development, testing, and establishment of native species for disturbed sites within NPS units. Some of the materials being tested and technology developed will have application to areas outside of park lands. An estimated 180-200 new indigenous ecotypes have been collected. These native species are now in the testing process or reproduction phase for use by parks and on other disturbed sites.

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INTRODUCTION

The National Park System of the United States comprises 356 parks covering almost 80 million acres in 49 states, the District of Columbia, America Samoa, Guam, Puerto Rico, Saipan, and the Virgin Islands. These areas are of such national significance as to be afforded protection by various acts of Congress.

Preservation of native plant genetic resources with their natural ecosystem is a high priority in the NPS. The National Parks recognize that historical and cultural landscapes are also important and worth protecting. To the extent possible, plantings in park units consist of species that are native to the park or that are historically appropriate for the event commemorated.

If possible, it is desirable to restore the native vegetation that was previously there before disturbance. Where disturbance is severe, restoration may have to begin at a lower successional stage and pioneer species considered.

The NPS/SCS Plant Materials Program initial focus is on development of native plants for the revegetation of areas disturbed by road construction. The NPS is planning construction or repair on approximately 200 miles of road. There are presently 15 SCS Plant Materials Centers (PMC) working on 38 park projects throughout the U.S.

PROGRAM OBJECTIVES

A cooperative agreement between the NPS and the SCS was developed in 1989. This cooperative Plant Materials Program seeks to draw upon the strengths of the two federal agencies in the increasing, testing, and establishing native species on disturbed sites within NPS units.

Method of pollination, seed dispersal, and plant longevity effect the common gene pool (genetic resources) of a species. In working with parks, general guidelines are suggested for seed collection where specific species information is not available:

1. Collect ecotypes in a general area having approximately the same flowering time,

2. Collect where site conditions are similar and ecotypes are not isolated by geographic or vegetative features.

3. Collect ecotypes with less that 600 to 1200 feet elevation range.

POINTS OF ORIGIN OF NATIVE PLANTS MAP

The use of specialized native plant species frequently is required in revegetation and restoration of disturbed lands. If the indigenous species for a specific area are not available, it may be necessary to use the nearest or best-adapted source where the point of origin is known.

PMCs have been collecting native seeds, testing plants, and developing seed sources and technology for conservation land uses since the 1930s. These native species are generally maintained at plant materials centers or through state seed certification in a manner that will ensure genetic integrity and identification.

Different species have gone through different methods in development. Some species are a direct increase of the particular ecotype; others may have gone through a selection process.

The SCS and NPS are publishing a map showing the "Point of Origin of Native Plants" for some 275 indigenous species developed by the SCS and cooperating agencies. This map and information will be available by March 1993. The map, together with the species list on the reverse side, will help to locate the closest available species of trees, shrubs, grasses, and forbs available for revegetation in parks and other specific sites. Plants are listed by state, with their origins shown on the map. The point of origin identifies a general location where the parent seed was initially collected.

SUMMARY

There are several positive spin-offs from this program. One of the intended benefits of the cooperative work with the NPS is sharing propagation technology. The SCS is planning to assemble new technology in a publication "Propagation of Native Plants for Revegetation" in 1993. This publication will contain 180-200 native species where previous information is lacking. The format will include collecting, cleaning, propagating, storing, and reestablishment information.

Some of the materials being tested and developed will have application to areas outside of park lands as well as technology being refined. An estimated 330-350 new park indigenous ecotypes have been collected. These native species are now in the process of testing or reproduction for use on park roads and other disturbed sites. The Plant Materials Program and information generated over the coming years will add to the base information and help develop parent seeds for locally adapted indigenous species. This and similar programs will help provide the needed revegetation technologies and biodiversity to improve restoration of natural ecosystems on disturbed sites.

The NPS park roads program with the Federal Highway Administration is the ideal starting point for the Plant Materials Program. Advanced scheduling and funding gives sufficient lead time to develop and complete plant production schedules. It takes three years lead time from seed collection to delivery of the first seed crop. Basic information about the development and growth habits of these plants is often lacking. Specialized vegetation and required techniques are tested and developed.

PARK PROJECTS

Prior to 1989, when SCS and NPS formally signed a memorandum of understanding, four centers were conducting plant materials work with specific parks. In 1990 and 1991 12 and 13 cooperative agreements respectively were initiated each of the two years. Nine agreements were signed in 1992 making a total of 38 projects to date.

Initially the cooperative plant materials projects focused on road related revegetation work. These projects vary in size from 10 to 120 acres. However, the technology and plant materials can be applied to other revegetation needs and to adjacent areas outside the parks. These agreements include working with a total of about 350-380 native plant species at PMC's across the U.S.

PROGRAM ACTIVITIES

The NPS/SCS Plant Materials Program functions can generally be grouped into four main activities:

1. Seeds are collected within the parks to preserve the unique characteristics of the original plant genetic diversity.

2. Seed and plants are grown and reproduced at centers located with approximately the same topography and climatic conditions.

3. New technology (testing and evaluating) is often needed to reproduce and grow these plants. New techniques are also tested to successfully use the native species.

4. Quality seed of known genetics along with the needed technology for establishment are returned to the park for use by resource managers.

The above activities may be shared between the SCS PMC's, individual parks, and commercial interest depending on species and needs.

It is proposed by some that preservation of genetic integrity (genetic resources) is the preservation of not only the full range of genotypes but, also the natural proportions of the natural interactions between genotypes. This interpretation and practical application of this policy can be very difficult to achieve.

TANGIBLE BENEFITS OF VISUAL SIMULATION IN MINE PLANNING AND PERMITTING

Craig Taggart

ABSTRACT

In the hands of experienced planners, credible visual analysis and accurate and defensible visual simulation can be of significant benefit to a company with a project in a sensitive setting. "What is looks like" is of increasing concern to an even more aware and active public. EDAW has been a leader in the development of accurate, defensible simulations for a variety of project types, including many controversial mining and superfund projects. Accurate and defensible visual simulation provides the basis for all parties -- the company, the public and the agency representatives -- to look together at an image with a common frame of reference, and judge the project on its true merits rather than on speculation and misunderstanding. And that alone is of tremendous value in gaining the understanding, support and approval needed for a smoother permitting process.

Visual simulation is also a useful tool in the internal project development and review stage. Companies can show great benefit by being aware of potential objections and developing appropriate actions which will present their project in a positive light. Visual simulation is an excellent interactive tool which allows a project proponent to develop and understand the tradeoffs of implementing alternative mining or reclamation actions prior to public and agency review. Not all projects are worthy of such effort, but for a project in a sensitive setting, companies can show real value by being proactive in heading off criticism, rather than later having to overcome opinions which have already solidified.

Whether for internal or public review, visual simulations for mine and reclamation planning (if accurately prepared) can provide positive and tangible benefit to the project proponent because of the ease with which they transmit complex information and facilitate positive interaction.

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INTRODUCTION

Human nature often leads us to perceive any proposed changes as larger and more disruptive than is usually the case. Accurate and defensible visual simulation provides the basis to look objectively into the future. All parties -- the developer, owner, agency representatives and the public -- can now look together at a proposed project with a common frame of reference, and judge a project on its true merits rather than on speculation and misunderstanding. Despite the perceived risks inherent in such an approach, EDAW has repeatedly found this approach to be of tremendous value in gaining the understanding, support and approval needed for a smoother permitting process.

Visual simulation is also a useful tool in the internal project development and review process. Planners, engineers and biologists can use visual simulations to evaluate alternative mine plan and reclamation schemes, assess potential project impacts, and develop appropriate modifications as desired. Visual simulation is a truly interactive tool that allows a project manager to develop and understand the tradeoffs of various alternatives himself before entering the maze of public and agency review.

THE TOOLS

Accuracy is the cornerstone of EDAW's state-of-the-art computer based visual imaging system. First and foremost, it has to be defensible; and accuracy is the key to its defensibility. As a result, there is important preliminary work that must take place in advance of the actual imaging process.

Seen-Area Analysis

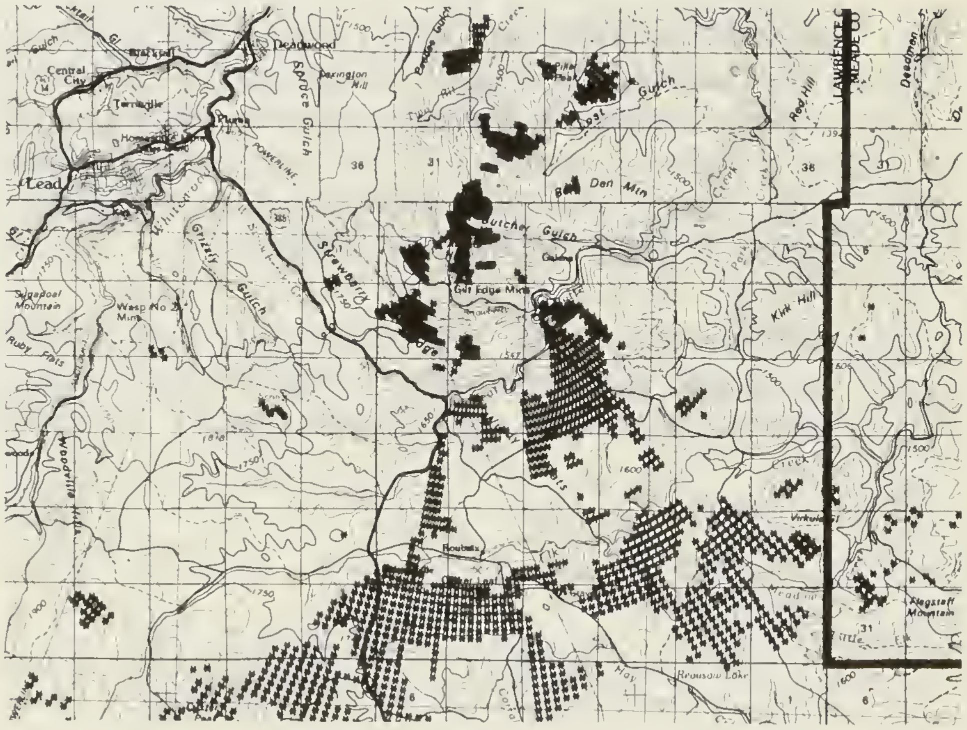

Figure 1. Seen-Area Map Example

The first step is to conclusively determine where the project may be seen from. Depending upon the terrain, it may be obvious for some projects; but as we'll see, you can be fooled. We've seen substantial public concern regarding projects that turned out to be only slightly visible or not at all visible from viewpoints of concern. For making an accurate and objective determination of seen area, we utilize an in-house terrain modeling and visibility analysis program. Usually, USGS 7½' topographic maps are used as the source for digitizing the surrounding terrain, which includes potentially affected viewpoints such as roads, recreation areas and residences. The most current version of the mine plan is used from which to digitize all or individual project features of concern. Computer printouts showing the seen-area, or area in view of a given feature or features, are then obtained at the scale of the source map and registered to it. Roads, recreation and residential areas potentially in view of that feature or features can then be readily identified. Figure 1 illustrates a seen-area map on a clear film base registered to the source map (in this case, a 1:100,000 regional scale map). This was done for the Brohm's Gilt Edge Mine near Deadwood, South Dakota. This image illustrates a not uncommon condition where, despite an early and widely held belief that this mine would be visible to a large area, we determined its visibility would be spotty and primarily limited to remote wooded areas. Later field reconnaissance, in fact, revealed that all portions of highways shown here as potentially visible are not visible due to vegetative screening. As indicated above, the computer seen-area analysis is based on terrain models and the influence of any additional screening provided by vegetation must be field checked. In conjunction with limited field reconnaissance, seen-area analysis provides an objective and defensible indication of areas which will or will not be affected by views of the project or individual project features.

3-D Perspective Plots

Although the seen-area analysis can objectively indicate those areas within view of a project, it does not provide any information on what the project would look like in terms of the amount seen or its scale and appearance in the context of the surrounding landscape. The next step is to identify the most critical or representative viewpoints and run 3-D perspective plots to illustrate the scale, context, amount seen and general character of the mine from these viewpoints. Figure 2 illustrates the nature of these 3-D plots, which is represented by a wire mesh draped over the model. This image is from our study of Goldenbell's Pinetree Mine in the Sierra Foothills west of Yosemite. The scale and extent of the two pits in the center as well as the waste rock terraces to the left (as seen from this highway viewpoint) are illustrated in this image. Such an image is suitable for planning and analysis purposes, and is quick and easy to produce for a variety of possible viewpoints. Such images can be highly useful in evaluating the effects of alternative layout and configurations of tailings, waste rock, and leach pad features. Again, they are objective, as accurate as the data used to create the models, and therefore entirely defensible.

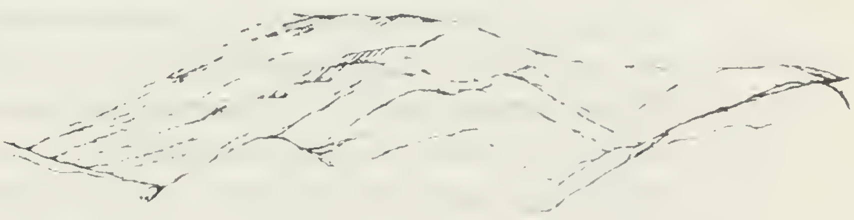

Figure 2. Computer 3-D Perspective

Visual Imaging

The next tool in the process is used for giving a greater level of realism to the model and the overall scene. This involves visual imaging or simulation. To assure accuracy, two elements are needed. The first is the terrain model (already discussed) which is used to assure location and scale accuracy of the final image. This is done by carefully registering the existing scene photograph with the computer 3-D model. Known reference points within each image are used for this purpose. When carefully followed, there is a direct sequence of objective steps which can be logically traced that demonstrate the scale and location accuracy of the final image. This process has stood up in countless studies in formal adversarial hearings and courts. I and others have served successfully as expert witnesses in such cases.

The second requirement is to assure that the image is realistic in its rendering quality; that such details as the stage and character of revegetation at the point in time the scene illustrates are faithfully represented; that the colors of rock, tailings and buildings are realistic and accurate, etc.

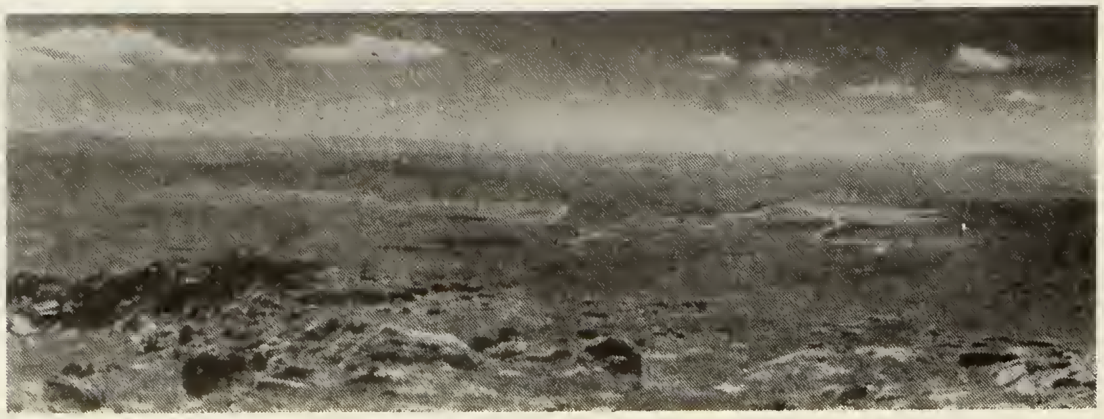

Figure 3. Photo Simulation Example

This step requires close coordination with mine engineers and reclamation specialists. The imaging can be done at two levels of realism -- sketch quality or photo quality. Figure 3 shows a photo simulation of the full buildout of a Nevada gold mine we are currently working on. The basis for its location and extent can be assured through the use of terrain models on which it is based.

Photo simulations are the best tool for accurately conveying a project to the public and agencies. The process is flexible and inexpensive enough that it is also a highly valuable planning tool. It only makes good sense that if you have a project in a sensitive setting that you understand what its visual effects will be. A mine plan involves complex planning and large scale operations. It is almost always enlightening to "see" your project ahead of time. Then, it puts you in the best position to head off possible ill-founded criticism objectively, accurately and early in the public review and analysis process. It also allows you to explore and evaluate alternatives beforehand.

PUBLIC/AGENCY ACCEPTANCE AND SMOOTHER PERMITTING

Some examples from previous projects will help to illustrate how the tools just presented and their application not only can, but have brought tangible results in the form of greater public/agency acceptance and smoother permitting for past clients. To help illustrate why these techniques are so effective, it is important to first understand the need. Three primary factors are at work here which I'll try to briefly explain by way of introduction followed by a few case studies.

Public Attitudes

I recently had occasion to review a Gallup Poll survey regarding public opinion on the environment. I've never personally put all that much faith in polls, but I was surprised to find that since the presidency of FDR, the difference between the latest Gallup Poll prior to an election and the voter results of that election were never more than 4 percentage points off, and were generally within 1 percentage point. So I reviewed the results from a new perspective. There were many questions asked in this 1991 nationwide survey and I can't relate them all, but I've summarized some of the most relevant points.

- The public believes environmental pollution is the third biggest problem facing America today (behind drugs and poverty/homelessness; slightly ahead of the economy and budget deficit, and well ahead of unemployment, education, AIDS and crime).

- 57% believe we cannot continue to live without major environmental disruptions without "immediate and drastic action."

- 83% believe business and industry are not worried enough about the environment.

- 28% say they have boycotted a company based on its environmental record.

- 91% believe protection of the environment should be given priority, even at the risk of curbing economic growth.

This is not to wave a red flag or say that every project is going to be subject to overwhelming public opposition. It does, however, provide evidence of an undercurrent of public concern about the environment, which should not be discounted whether or not you agree with it. The intensity of the last statistic in particular is overwhelming. It shouts of the frustration of years of conflict of extremes between industry and the environment without recognizing the middleground. Its implications are profound and, in my opinion, dangerous. Much more could be said about this, but the point in my mind is that a company with a project in a sensitive setting cannot afford to be naive or unprepared for attitudes they will face. Without thoughtful planning and the communication necessary to convey a company's good intent, we are destined to see the extremes become even more polarized, which is in no one's interest.

Visual Appearance

George Turcott, a past BLM Assistant Director, once said that people would judge the success or failure of projects on BLM land more by the way they look than any other factor. That is not to say that desert tortoises, tipi rings, and clean water don't have value to society, but simply that the vast majority of people will judge a project by what is most noticeable -- most often that is its overall visual appearance in context to the surrounding landscape. I have always believed that, but I thought I'd try a little survey to test that theory. Figures 4a and 4b contain images which should be familiar to you, since they are from the front and back cover of the program for this conference. Associated with each is a summary of responses to a survey which was given to 32 people from a variety of backgrounds and occupations. They were asked the following: "Imagine yourself driving through country typical of that shown in each of the accompanying two scenes. Study each of the scenes for a minute, then briefly indicate what your likely reactions, thoughts and impressions would be to each scene. Provide up to three comments each." No further explanation was provided. Eighty-one responses were provided to Scene A and 82 responses were provided to Scene B.

Figure 4a. Perception Survey, Scene A

SCENE A

Number Comments	Nature of Comments
17	Buffalo (virtually all positive)
13	Attractive, beautiful
8	Peaceful
8	Natural environment
7	Big/interesting rocks
5	Interesting/desirable landscape character
5	Native/green grasslands
4	Unnatural background landforms
3	Would stop to observe or take pictures
2	Successful reclamation/adjacent reclamation
2	Will next generation be able to experience this?
6	Miscellaneous--healthy, private, cold, bright

Figure 4b. Perception Survey, Scene B

SCENE B

Number Comments	Nature of Comments
21	Ugly/unattractive
18	Environmental problems (general, erosion, polluting, wildlife, etc.)
10	Should be reclaimed
7	Wondered what kind of minerals/rocks
5	Wondered about the operation itself
4	Profit motivated damage/greed
4	Extent of excavation/damage
4	Striking color contrast
2	Positive economic influence
2	Difficult to reclaim
5	Miscellaneous--poor planning, trailer,

Several observations can be drawn from this, not the least of which is to make sure you put enough money in your reclamation budget to buy a small herd of buffalo. Evidently it can cure a host of ills. Additionally, it confirms the obvious, that a landscape (and project) will be judged based on its visual character -- if it generally looks intact, it will be judged positive; and if it looks disturbed, it will be judged negatively. Some additional observations of interest are that not only was Scene A judged to be attractive, it was thought to be natural or native and a place with desirable character. Two individuals even wondered if such places would still exist for the next generation. Only four individuals recognized the unnaturalness of the background and only two judged this to be a mine reclamation site. This not only speaks well to the excellent reclamation work which was done here, it clearly points out the value of simulation to a mining company in being able to objectively and defensibly illustrate their plans for a productive post mining landscape. Despite the possibility of lingering environmental problems, the vast majority of people will judge a productive and apparently healthy landscape like this to, in fact, be healthy.

Alan J. Gilbert, of Sherman & Howard in Denver, presented a paper at the Fourth Western Regional Conference on Precious Metals and the Environment held in Lead, South Dakota in 1990, entitled "How to Mine and Reclaim to Avoid CERCLA Liability." In this paper, he stressed the comprehensive and far-reaching nature of this law and the difficulty of avoiding liability under it. He did offer a number of suggestions which, in total, add up to what amounts to responsible business practices. He offered in part:

> *"As lightening strikes seek out high ground and tall structures, CERCLA law suits often seek out defendants who have in some way greatly upset the government or some other plaintiff. One therefore becomes a CERCLA defendant because a plaintiff is motivated to pursue extensive and lengthy proceedings against you. The best way to avoid CERCLA liability is thus to avoid motivating the plaintiff in that fashion. This strategy requires attention to operational matters which are not typically the first priorities to the mine operator."*

He then goes on to offer the following:

> *". . . work with state reclamation agencies closely, and give the government substantial comfort that you are carefully doing what you ought to do . . . It is very important in order to reassure the government at least, to plan carefully how to clean problem areas. . . To avoid CERCLA liability, therefore, it is advisable to avoid reaction alone, and to show the government carefully planned solutions to environmental problems."*

And regarding non-governmental plaintiffs, Mr. Gilbert said:

> *". . . ordinary citizens (as well as environmental groups and others) have the ability to bring a cost recovery action (or an enforcement action) under CERCLA. Therefore, in order to avoid CERCLA liability, the mine operator must be aware of citizens' power and take steps to avoid such lawsuits. In essence, this area involves the relationship between the operation and those affected by it. Public relations, good housekeeping practices, and fair dealing are all important ingredients to this strategy."*

The ability to plan effectively and then to visually demonstrate the good intent of your planning through simulations of a productive post mining landscape is a very important component in the strategy recommended above.

Regarding Scene B from our survey, not only was this scene regarded as ugly and distasteful, there was a nearly one-to-one correlation of its unsightliness with suspected broader environmental damage. Where there's smoke, there must be fire. Here too, simulations can help. A simulation showing an orderly, well operated mine can provide not only an image of efficiency, but can provide the basis to illustrate and discuss planned damage control measures with outside parties as appropriate.

An interesting side light in the responses to Scene B is that while every respondent but one felt that it was negative overall, there were 16 positive responses, indicating interest in the rock, the colors, or the operation itself. We have held the view for some time that despite the fact that while active, a mine necessarily involves large scale landform and vegetative modifications that are often seen as negative, people will find a greater degree of acceptance for it if they understand it. We have developed interpretive material and site developments (Figure 5) for a large number of facilities, including mines, and have always found a much higher degree of public acceptance once they understood something about what is going on (what's being mined, how it's mined and processed, what it's used for, why here, what's being done to reduce potential impacts, etc.) and what will go on in the future (what's planned for the site following reclamation and how it will be accomplished). Instead of allowing the image of a corporation forever destroying the land for short-term personal gain to achieve a foothold, it promotes the image of a responsible company developing resources which benefit society while planning for the return of a landscape with long-term usefulness and productivity.

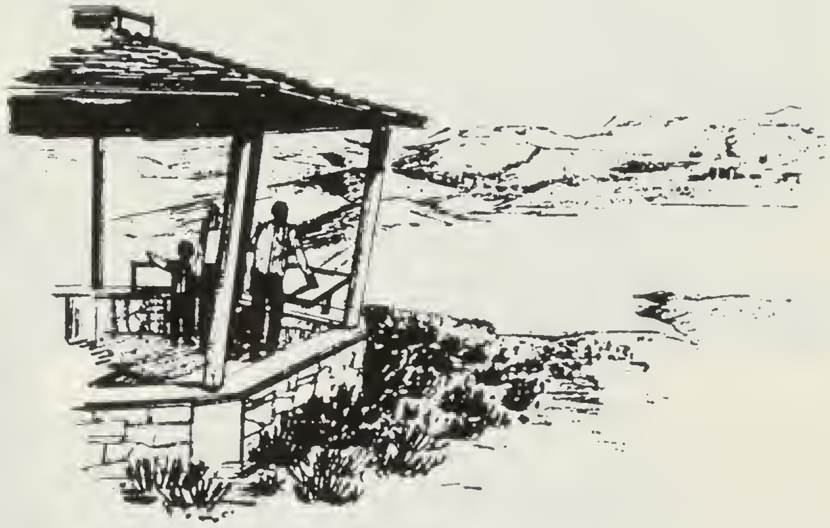

Figure 5. Interpretive Site Concept

The Fear of the Unknown

Imagine yourself traveling through a remote part of the Nevada desert by jeep. You see a small, isolated mountain range in the distance, so you head toward it. And as you come closer, you see an old mine portal braced up with wood timbers and it doesn't look like anyone has been here in many years. It's immediately inviting, but you hesitate. On one hand, you are tempted to go in and explore -- it's obviously very old and maybe there would be some relics inside. Also, it's quite hot out and it might be cool inside. But it's dark and you don't know what's in there. As you consider whether or not to enter, you might reasonably have legitimate concerns about rattlesnakes who also might be seeking refuge from the sun, poison gas, unseen vertical shafts or cave-ins. I suspect if you're like me, that despite our interest in exploring or getting out of the sun, we'd decide the best option is to take a couple of pictures and pass it by. The reason being that we don't know what is inside. It's the fear of the unknown that keeps us out, despite our conscious desire to go in and explore.

In my experience, it is precisely that fear of the unknown that is behind what often appears to us as unreasonable opposition to a project. It happens over and over again. In fact, with virtually every project we work on, fears and therefore opposition run higher than is appropriate because of a lack of understanding. And with the lack of understanding, it is human nature to imagine a project more disruptive and damaging than will be the case. And in virtually every project we have been involved with where we have used some combination of the visual analysis tools previously identified, fears and opposition to the project have dropped dramatically and understanding and acceptance have risen substantially. When the public and decision makers can be given the clear understanding of what to expect in a defensible and objective manner, hearings and permitting are made measurably easier.

Let me illustrate with three selected project examples. Imagine yourself in the role of the public or agency as I describe the relevant facts. You then judge whether (from this perspective) it sounds like a project with the potential for significant impacts, and I'll explain our role and the outcome.

Case Study #1 -- Pinetree Gold Mine


Figure 6. Pinetree Mine Photo Simulation

The project is located in the Sierra-Nevada foothills approximately 60 miles west of Yosemite National Park adjacent to Highway 49 just above the Merced River. This project involves excavation of two major pits, both in view of the highway and a BLM recreation road. Portions of Highway 49 will have to be relocated. The two pits will cover approximately 140 acres and result in extensive vertical highwalls. The tailings pond will cover approximately 170 acres. The waste rock area will cover approximately 200 acres in four terraces on the mountain side above the Merced River, and will be visible from a substantial segment of Highway 49 at both long and close-up viewing distances. Substantial public opposition to the project exists and the County Planning Commission (local permitting agency) is divided.

For this study, we prepared a terrain model and generated 3-D perspective views from three sensitive viewpoints (two from Highway 49 and one from the BLM recreation road). We produced enlarged photo simulations from all three viewpoints (see Figure 6) and conducted a BLM contrast rating. In addition, we prepared a series of interpretive exhibits for the Mariposa County Fair dealing with the history of mining in the Sierra and about the proposed Pinetree project in particular.

The outcome was that virtually all public and agency controversy regarding the visual impacts of the proposed project were quieted despite the sensitive setting this project was planned for.

Case Study #2 -- Blue Diamond Pumped Storage Project

The project is located on an isolated ridge approximately two miles from and in direct view of portions of the Red Rocks National Conservation Area to the west. Within five miles to the east is the residential outskirts of the City of Las Vegas, which is quickly expanding to the west in the direction of the proposed project. Two state highways are within three miles of the site. The project involves creation of a 40-acre reservoir atop the ridge, another 37-acre reservoir below the ridge towards Las Vegas accompanied by penstocks a power house and a substation. Power would be fed into the municipal grid by a new 138kv power line which would run between the plant and the urban area. Public concern is mixed, while the BLM and Clark County officials are seriously concerned about the visual impacts to both the National Conservation Area and the outlying Las Vegas residential area.

EDAW prepared a seen-area analysis from various independent project features because of their separated nature and the broken nature of the terrain. This confirmed visibility of the upper reservoir to portions of the National Conservation Area and indicated visibility to roads and the outlying residential areas to the east as well. It also objectively demonstrated that there would be no visibility to the highway. Portions of the lower reservoir and transmission line were also confirmed to be in view of roads and residential areas in the vicinity. Simulations were then prepared from both the recreation area and portions of the outlying residential areas where views were expected to be most critical.

Figure 7. Blue Diamond Project: Existing Conditions (top) Photo Simulation (bottom)

The outcome was that the simulations, which were based on a computer model (as always), illustrated objectively that although the project could be seen from certain critical viewpoints (as evidenced by the seen-area analysis), the terrain was broken enough and the angles of view such that very little of any given project feature could be seen in views from the Las Vegas area. From the Red Rocks National Conservation area, the 3-D wire frame perspective plots illustrated that the entire 40-acre upper reservoir would be seen. However, the photo simulations that were produced from them demonstrated that due to a combination of distance, existing disturbance in the area, and a careful choice of colors, the upper reservoir would be very difficult to detect (Figure 7, look closely, it's there). The agencies were at once satisfied that the project would not result in any meaningful level of visual impact.

Case Study #3 -- Alton Coal Mine

This study was not conducted by EDAW; however, I was the project manager while with another consulting firm. The project is the development of the Alton Coal field which covers 60 square miles, about half of which is located in the Alton East track along the south side of Bryce Canyon National Park. Yavimpa Point, which is a popular overlook in the park, directly overlooks the coal field in the middleground with views extending many miles to the south and east. A USGS sponsored EIS contained a photo simulation inaccurately representing the condition of the landscape at the height of mining. It illustrated a nearly continuous and extensive band of highly contrasting disturbance throughout the coal field. The Park Service was highly concerned; the BLM and Forest Service were concerned as well. Various national environmental groups were in strong opposition to the project, and the project was facing OSM unsuitability hearings.

The USGS sponsored simulation was highly flawed and based on impressions rather than as the result of any systematic or defensible process. Our analysis involved an accurate determination of the visible portions of the mine through a seen-area analysis, the development of accurate 3-D computer perspectives, accurate determination of the surface and subsurface landscape conditions and colors, an accurate determination of the mining and reclamation sequence over time, and the development of an accurate and defensible photo simulation taken from Yavimpa Point.

Instead of the entire coal field being declared unsuitable as was feared, only a small percent nearest the Park and where economic recovery was most marginal was declared unsuitable.

Certainly, these successes and those of many, many other projects cannot entirely be attributed to our work. However, almost without exception, it has been our experience that substantial opposition can be and has been successfully and effectively overcome when the public and agencies stop reacting to the unknown and are presented with accurate, defensible and objective information. It has rarely taken away all objection, but it has virtually never failed to reduce opposition enough to provide a large margin of rational thought to enter so that intelligent and informed decisions could be made.

SIMULATION AS A RECLAMATION PLANNING TOOL

I've talked mostly about simulation as an analysis tool, something to facilitate project engineering or something used as a last resort. It is my feeling that we can most productively use simulation as a tool to facilitate reclamation planning. We are currently involved in two projects where we are using simulation to display, evaluate and compare alternative reclamation plans. These include a proposed copper mine in Arizona and an existing tailings disposal site in New Mexico. We have done the most work in this area for ARCO on some of their superfund sites, Warm Springs and Butte-Silverbow Creek in Montana, and Copperton in Utah. We're very excited and proud of the leadership ARCO is showing in this area and our involvement with them. Figure 8 includes three images. The top image is a photograph of existing conditions at the Silverbow Creek site. Because of its location adjacent to the Town of Butte, ARCO was willing to consider nontraditional reclamation measures. The middle image shows a reclamation plan developed by EDAW. As shown, the plan includes realignment of the creek, consolidation and removal of tailings, a creekside trail, historic interpretive sites, and parking and picnic areas. This plan represents a preliminary alternative, and planning is still underway, being influenced most heavily by larger planning considerations involving the consolidation interrelationships of the various disposal sites in the area. This project best illustrates the value and potential of wise and creative reclamation planning. It will represent the large scale transformation of a neglected and troublesome landscape to one which is not only stable and productive, but one which becomes an attraction and asset to the community.

The cleanup of superfund sites such as this is enormously expensive. The amount spent to incorporate good planning and the tools to explore and illustrate reasonable alternatives on the other hand is very insignificant. But as this project illustrates, the value can be tremendous in both good planning and the good will which results from it.

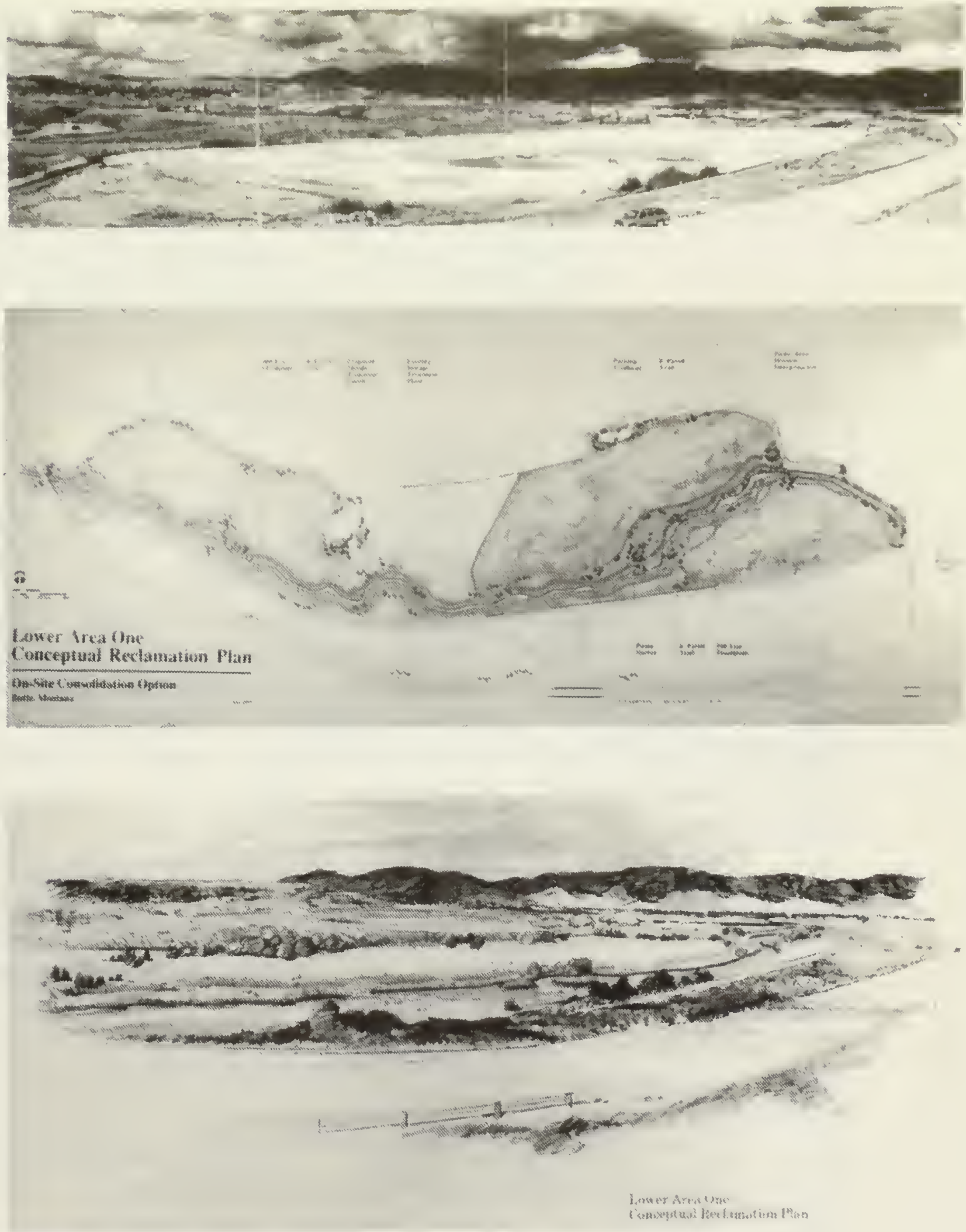

Figure 8. ARCO Silverbow Creek

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

RELATIONSHIP BETWEEN SOIL SELENIUM CONCENTRATIONS AND SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING

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ABSTRACT

Agronomic selenium (Se) information is generally more abundant than information from mined or reclaimed areas. Advanced laboratory techniques have refined detection limits and provided new information on Se levels within current mining areas. Due to the move towards redefining suitability limits in backfill and topsoil at surface coal mines, updated information is needed by regulatory agencies and industry. Current Wyoming "regulated" level for suitable Se concentrations in backfill and topsoil at surface coal mines is 0.1 ppm extractable Se. The Wyoming Department of Environmental Quality - Land Quality Division, recommended procedures for soil Se determination include AB-DTPA and Hot Water extractable methods. In addition to the lack of information on soil/backfill Se at surface coal mines, little information is available on the relationship of reclaimed area plant uptake of Se on either of the two state recommended methods of extraction. A three year study was initiated in 1991 to investigate the relationship of plant Se uptake and soil Se levels determined by five methods: Total Se and AB-DTPA, Hot Water, Saturated Paste, and Potassium Phosphate extractable. Soil and vegetation samples were collected in 1991 and 1992. Linear regression analysis was run on all five methods of Se determination. Results of these analyses are presented.

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INTRODUCTION

During the mid 1970's and early 1980's, surface coal mining in many western states expanded rapidly. One of the resulting major coal regions includes the Powder River Basin of northeastern Wyoming. Currently, 21 proposed or active mines lie on a basic north-south trend within a 1,800 square kilometer area surrounding the towns of Gillette and Wright, Wyoming.

Overburden material within this region is from the Fort Union Formation and is composed primarily of Cretaceous shales that were deposited in a marine environment. As a result of the marine deposition, certain chemical characteristics are evident, including salinity and deposits of elements such as Se.

In the past 10 years, significant attention has been given to Se in agronomic situations (Bainbridge, et al, 1988; Bainbridge, 1990; and See, et al., 1990). Associated animal nutrition studies have shown that plant Se at 5 ppm has detrimental effects to animals consuming these plants over long periods of time (National Academy of Sciences, 1976). However, it has only been recently that Se within the reclaimed environment has been addressed. Industry personnel and state regulators are seeking ways to determine the relationship between pre- and post-mining soil/backfill Se levels and resulting plant Se concentrations.

The Abandoned Coal Mine Lands Research Program (ACMLRP) funded an intensive three year study, initiated in May, 1991. The purpose of this study was to determine the relationship between soil Se levels and plant Se concentrations. Concurrent ACMLRP research at the University is being directed at different facets of the Se issue including the importance of solid and solution speciation of Se on mined lands, the role of organic solutes on the mobility of Se, and the toxicology of chronic selenosis in Wyoming grazing animals.

Fieldwork was conducted on one abandoned mine site near Sheridan, Wyoming and two active mines south of Gillette, Wyoming within the Powder River Basin coal region of northeastern Wyoming. The two active mines consist of one large mining operation (Mine L) and one small mining operation (Mine S).

Full scale soil and vegetation sampling was conducted in 1991 and 1992. A reduced, yet representative, subset of 1991 sample locations were resampled in 1992 for soils analysis. This reduced sampling was conducted to provide soils information continuity over the three year study.

Twenty-three native locations were sampled in 1991. They were sampled twice in 1992 for vegetation Se levels. Reclaimed area sampling locations were reduced from 91 in 1991 to 52 in 1992. Primarily sites with extremely low 1991 levels of Se were deleted in the 1992 sampling program. This targeting of areas with moderately detectable Se levels for the 1992 sampling program was designed to increase the probability of finding detectable plant Se values and allow vegetation information continuity over the three year study, while focusing on the overall purpose of Year 2, i.e., determine if seasonality affected the levels of plant uptake of Se. Samples were collected the end of May and during the early part of July. For purposes of this paper, only information from the two active mines will be presented.

The main objective of the three year study was to examine plant and soil Se in abandoned, reclaimed, and native sites to determine if a statistical relationship could be identified. Secondary objectives within the overall main objective included (not necessarily in order of priority): 1) identify laboratory analytical procedures that provides consistent, repeatable information; 2) identify the possible Se forms that play a major role in the uptake of Se by plants; 3) identify other dependent variables that may play a role in plant uptake of Se other than soil level Se and quantify that relationship with the appropriate regression function; 4) determine Se uptake differences between native and reclamation species; 5) determine the effect of soil depth on plant uptake of Se; and 6) recommend Se backfill suitability limits for reclaimed areas in the Powder River Basin of northeastern Wyoming.

This paper will primarily focus on results of the 1991 sampling program. It is important to note that information reported in this paper is preliminary. The project includes the 1993 sampling program; a final summary will be forthcoming at the end of the three year project. Final statistical regression analysis of collected 1991 independent variables will be presented at the March meetings.

METHODOLOGY

Soil and vegetation sampling was conducted on native and reclaimed areas within the two active mine permit areas. Sample locations were randomly chosen within native areas to represent all vegetation types present on the active mine permit areas. For the reclaimed areas, sample locations were chosen within various aged areas to provide information on site age, plant maturity, percent cover, and other variables. Sample locations were marked with steel fence posts, which were located 25 feet south of the actual sample location, to prevent any deleterious effects from grazing animals. A total of 23 native (13 from Mine L and 10 from Mine S) and 87 (79 from Mine L and 8 from Mine S) reclaimed areas were sampled during 1991. Twenty-three and 52 native and reclaimed area sites, respectively, were sampled in 1992.

During the soil sampling program of 1991, three holes were sampled at each site using a triangular pattern with holes one meter apart. This was conducted to provide information on the variability of Se data within a narrow area at each site. The triangular area was randomly oriented to prevent bias that may result from a consistent compass direction orientation. Within native areas soils were sampled by horizon to a maximum depth of 1.5 m. Within reclaimed areas, soils were sampled based on topsoil replacement depth, and 0-0.6 m and 0.6-1.2 m of underlying backfill material.

Based on the 1991 analysis of all three holes per sample location, it was determined that variability was generally low, based on the coefficients of variability, and only one hole would be required for sampling during the 1992 subset sampling and 1993 full-scale sampling. For total Se, coefficients of variability ranged from approximately 17% on reclaimed areas to approximately 25% on native areas. Therefore, during 1992, a selected number of holes were resampled within high, medium, and low Se sample locations, based on 1991 data. All soil samples were sent to Intermountain Laboratories for processing and analysis of AB-DTPA and hot water extractable Se. The University of Wyoming provided the following data: pH, electrical conductivity, sulfates, saturated paste Se, and phosphate extract Se. Quality control between laboratories was provided by 20% duplicate analysis of a given parameter by the other lab not responsible for the analysis of the major portion of that parameter.

Native areas were sampled by soil horizon. Statistical analysis was conducted on approximate weighted average values for depths within native areas consisting of the following: depth 1) 0 - 0.3m; depth 2) 0.3 - 0.6m; depth 3) 0.6 - 0.9m; depth 4) 0.9 - 1.2m; and depth 5) 1.2 - 1.5m. Depths used for statistical comparisons within reclaimed areas consisted of the following: depth 1) replaced topsoil; depth 2) 0 - 0.6m of regraded backfill; and depth 3) 0.6 - 1.2m of regraded backfill.

Full scale vegetation sampling was conducted at each of the 99 sample locations in 1991. A five to ten gram vegetation sample was collected within a 3.5 m radius from the center of the site. Sampled plants included the dominant four species based on a visual determination of relative site cover and a composite grass sample designed to simulate herbivore grazing. General plant cover was subjectively estimated using a system that grouped plants into the following gross cover percent categories: <1, 1-10, 11-25, 26-50, 51-75, and 76-100%.

Sampled vegetation was place in pint size Ziploc storage bags and immediately placed on ice. Samples were frozen within ten hr of collection, at the end of each sampling day.

Samples were taken to the University of Wyoming and kept frozen until samples could be dried and ground. Samples were dried at 50-60 degree Celsius, to prevent Se loss during drying, for 24 hr in a forced air oven and then ground to 60 mesh using a plant grinder (A. H. Thomas Company). Samples were then sent to Intermountain Laboratories in Sheridan, Wyoming, for total Se analysis.

RESULTS

In 1991, a total of 13 and 79 locations were sampled for vegetation within native and reclaimed areas, respectively, at Mine L, whereas 10 and 8 native and reclaimed areas, respectively, were sampled at Mine S. This translates to a total number of 1991 vegetation samples collected from Mine L of 389 and 100 from Mine S.

Since some of the sites contained primary Se indicator plants such as *Astragalus bisulcatus* that were sampled for analysis, some outlier points for total Se analysis, i.e., extremely high values compared with the majority of points, are present within the data. To avoid skewing the data toward these obvious outliers, medians were calculated instead of means. Within the 1991 sampling, the median for all sampled vegetation species, including the composite grass sample, was 0.30 and 0.85 ppm within native areas and 0.65 and 0.50 ppm within reclaimed areas at Mine L and Mine S, respectively.

Vegetation species that exceeded 5 ppm during 1991 included: *Astragalus bisulcatus* (2 individuals) from Mine L native sites; *Agropyron smithii* (1), *Atriplex canescens* (2), and *Onobrychis viciaifolia* (1) from Mine L reclaimed sites; *Agropyron dasystachyum* (1), *Koeleria macrantha* (1), *Vicia americana* (1) *Xylorhiza glabriuscula* (1), and *Gutierrezia sarothrae* (2) from Mine S native sites; and *Bromus inermis* (1), *Taxaxacum officinale* (1), and *Astragalus bisulcatus* (1) from Mine S reclaimed sites.

High soil Se levels were not necessarily present at sites that produced vegetation with Se in excess of five ppm. Two sites in Mine L native areas and one in a Mine S reclaimed area, all containing high *Astragalus bisulcatus* Se levels, showed extractable soil Se levels of <0.02 ppm at most depths for both hot water soluble and AB-DTPA extractable Se. *Astragalus bisulcatus* is a primary Se indicator species that can extract Se from low-level soils and is generally non-palatable.

One native area at Mine S, having consistently high vegetation levels, had soil levels in excess of 0.30 ppm at depths greater than 0.3 m for both hot water soluble and AB-DTPA extractable. The few high plant values on reclaimed areas at Mine L generally reflected high Se values at depths greater than 0.6 m.

All soil samples were analyzed for AB-DTPA extractable Se, whereas hot water extractable Se analysis was run on a selected number of soil samples. Based on a specific review of reclaimed areas at Mine L, total soil Se values averaged 0.99 ppm over all sample locations regardless of depth. Hot water soluble soil Se values averaged 0.16 ppm, while AB-DTPA extractable Se averaged 0.11 ppm. Based on a specific review of native areas at Mine L, total soil Se values averaged 0.75 ppm. Hot water soluble soil Se values averaged 0.03 ppm, while AB-DTPA extractable Se averaged 0.04 ppm (Table 1).

Based on a specific review of reclaimed areas at Mine S, total soil Se values averaged 1.45 ppm over all sample locations regardless of depth. Hot water soluble soil Se values averaged 0.13 ppm, while AB-DTPA extractable Se averaged 0.14. Based on a specific review of native areas at the smaller coal mine, total soil Se values averaged 1.55 ppm. Hot water soluble soil Se values averaged 0.14 ppm, while AB-DTPA extractable Se averaged 0.16 ppm (Table 1).

Simple correlation analysis was conducted on the four extracted 1991 soil Se concentrations and total Se versus the resultant 1991 plant Se concentration of each lifeform category (grass, forb, and shrub) and the composite sample, based on an overall average. A brief summary of correlation coefficients for the three main lifeform categories, i.e., grass, forb, and shrub, above are presented in Table 2. Correlation coefficients ranged from the 0.3 to 0.7.

DISCUSSION

Current results on the possible relationship between soil and plant Se levels are generally inconclusive, based on the preliminary correlation coefficients. Multiple regression analysis will be run on the data using SAS (SAS 1990) on the University of Wyoming mainframe computer. Various combinations of independent variables (e.g., pH, electrical conductivity, SO_4, total soil Se, hot water soluble Se, AB-DTPA extractable Se, saturated paste Se, and PO_4 extractable Se) and dependent variables (e.g., plant level Se by various lifeforms or individual species) will be analyzed to derive more appropriate and useable regression coefficients. However, it may be that the necessary independent variables to characterize plant Se were not measured. Known values such as age of the reclaimed area or precipitation amounts will be added to the overall database to provide additional independent variables that may aid the characterization process. A formal summary of the three year project will be forthcoming after the 1993 sampling program.

One of the preliminary observations that is evident from the data is the variability between reclaimed and native areas and within native areas, based on the dominant vegetation type. Reclaimed areas, by virtue of the overall mining process, tend to produce relatively homogenized topography, backfill, and replacement topsoil on a gross scale. However, on a microscale, seleniferous material may be present in localized pockets and produce seleniferous vegetation within a relatively small area or within a specific sampling location.

Reclaimed areas at Mine S contained lower Se values than native areas at Mine S (Table 1) while reclaimed areas at Mine L contained higher Se values than native areas at Mine L. This may be explained in part due to the fact that many of the native area points are located in breaks topography at Mine S, unlike the native areas at Mine L which are located in grassland or big sagebrush areas. Overall values (Table 1) are higher at Mine S.

Site specific weather conditions may have also played a role in the seasonal variability of Se. Weather within the Powder River Basin during 1991 was unusually cool and wet during April and May and extended to the end of June. Sampling date within a given year or between years will be an important consideration.

A summary of selected plant species is found in Table 3. Western wheatgrass was a common species throughout all four sampled areas. At Mine L, the mean vegetation Se content of western wheatgrass was higher in the reclaimed area sites (1.15 ppm) than native sites (0.42 ppm). At Mine S, the mean vegetation Se content of western wheatgrass was lower in the reclaimed area sites (0.97 ppm) than native sites (1.30 ppm).

Acknowledgement

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Table 1. 1991 Soil Se Analysis Summary[1].

Sampled Area[2]	Total Selenium	Hot H_2O Selenium	AB-DTPA Selenium
L-R[3]	0.99 ± 0.39	0.16 ± 0.12	0.11 ± 0.10
L-N	0.75 ± 0.45	0.03 ± 0.03	0.04 ± 0.03
S-R	1.45 ± 0.69	0.13 ± 0.09	0.14 ± 0.09
S-N	1.55 ± 0.69	0.14 ± 0.12	0.16 ± 0.11

[1] Soil Se levels are means ± 1 S.D.; calculated by sample location regardless of depth.

[2] L-R = Large Mine Reclaimed Area; L-N = Large Mine Native Area; S-R = Small Mine Reclaimed Area; S-N = Small Mine Native Area.

[3] Higher hot water soluble Se value over AB-DTPA value may be due, in part, to number of sample sites and locations, i.e., 32 for hot water soluble and 73 for AB-DTPA.

Table 2. Correlation Coefficient Summary between Vegetation Lifeforms and Total Se and Selected Extracted Se Levels.

Sampled Area	Lifeform Category[1]	Depth[2]	Total Se	AB-DTPA Extracted Se	HWS[3] Extracted Se
Native	Grass	1	N.S.[4]	N.S.[4]	N.S.[4]
		2	0.44	0.75	0.77
		3	0.36[5]	0.74	0.50
		4	N.S.[4]	0.65	0.72
		5	N.S.[4]	0.60	0.66
Reclaimed	Grass	1	0.53	N.S.[4]	N.S.[4]
		2	0.73	N.S.[4]	0.59
		3	0.70	0.35[5]	0.60
Native	Forb	1	0.30[5]	N.S.[4]	N.S.[4]
		2	N.S.[4]	N.S.[4]	N.S.[4]
		3	N.S.[4]	N.S.[4]	N.S.[4]
		4	0.36[5]	N.S.[4]	N.S.[4]
		5	0.35[5]	N.S.[4]	N.S.[4]
Reclaimed	Forb	1	0.56	N.S.[4]	0.54
		2	N.S.[4]	N.S.[4]	N.S.[4]
		3	N.S.[4]	N.S.[4]	N.S.[4]
Native	Shrub	1	N.S.[4]	N.S.[4]	N.S.[4]
		2	N.S.[4]	0.57	0.58
		3	N.S.[4]	0.61	0.35[5]
		4	N.S.[4]	0.58	0.67
		5	N.S.[4]	0.48	0.53
Reclaimed	Shrub	1	0.42[5]	N.S.[4]	N.S.[4]
		2	0.56	0.61	0.53
		3	0.66	0.63	0.57

Table 2. Correlation Coefficient Summary between Vegetation Lifeform and Total Se and Selected Extracted Se Levels. (cont.).

Sampled Area	Lifeform Category[1]	Depth[2]	Total Se	AB-DTPA Extracted Se	HWS[3] Extracted Se

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[1] Average of all individuals, except grass which includes composites.

[2] Native Depths:
1 - 0 to 0.3 m
2 - 0.3 to 0.6 m
3 - 0.6 to 0.9 m
4 - 0.9 to 1.2 m
5 - 1.2 to 1.5 m

Reclaimed Depths:
1 - replaced topsoil
2 - 0 to 0.6 m of regraded backfill
3 - 0.6 to 1.2 m of regraded backfill

[3] Hot water soluble.

[4] N.S. = Not Significant

[5] Signifies correlation at the 0.05 level, all others at 0.01.

Table 3. Selected Plant Species[1] Summary of Selenium Range, Mean, and Standard Deviation for 1991 Data.

Sampled Area[2]	Plant Species[3]	Total # Plots	Total Plots w/Plant #	%	Range of Values (ppm)	Mean ± 1 S.D. (ppm)
L-R	Agrsmi	71	45	63.4	0.05-5.00	1.15 ± 1.28
	Medsat	71	49	69.0	<.01-2.50	0.78 ± 0.64
	Atrcan	71	15	21.1	<.01-21.25	4.06 ± 5.60
L-N	Agrsmi	10	3	30.0	0.25-0.65	0.42 ± 0.21
	Astbis	10	2	20.0	34.00-37.00	35.50 ± 2.12
	Arttri	10	5	50.0	0.20-0.50	0.36 ± 0.11
S-R	Agrsmi	8	8	100.0	<.10-3.80	0.97 ± 1.34
	Ratcol	8	2	25.0	0.15-0.50	0.33 ± 0.25
	Atrcan	0	0	-	-	-
S-N	Agrsmi	10	6	60.0	0.25-3.10	1.30 ± 1.00
	Gaucoc	10	1	10.0	1.00	-
	Artfri	10	3	30.0	0.60-0.90	0.75 ± 0.15

[1] Plant species selection based on relative abundance within specific reclaimed or native area; information collected in June, 1991.

[2] First letter designates mine; second letter designates reclaimed or native.

[3] Agrsmi = *Agropyron smithii* (*Pascopyrum smithii*)
Medsat = *Medicago sativa*
Atrcan = *Atriplex canescens*
Astbis = *Astragalus bisulcatus*
Arttri = *Artemisia tridentata*
Ratcol = *Ratibida columnifera*
Gaucoc = *Gaura coccinea*
Artfri = *Artemisia frigida*

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PRODUCING AN EXTRACTABLE SELENIUM STANDARD FROM SPOIL MATERIAL FOR USE AS A CONTROL SAMPLE

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ABSTRACT

There is a need for an extractable standard for selenium analysis in soil/spoil material. Shelf life, different extractable methods and different methods of analysis have caused varying results from laboratories without a control sample available. A fresh spoil sample was collected, processed, and analyzed over time. The same methods of extraction and analysis were used. The results of this study will be presented.

Inter-Mountain Laboratories, Inc.

INTRODUCTION

Two fresh spoil samples were collected from a freshly blasted high wall of a southern Powder River Basin coal mine. Two separate strata were sampled. The spoil material had been previously sampled and values in the range of 0.05 to 0.30 ppm selenium were obtained by laboratory analysis. The material was then shipped as 2 common bulk samples to our laboratory located in Sheridan, Wyoming. The samples were received and crushed by a chipmunk jaw crusher to minus 3/4" size.

The samples were identified as samples A and B, and air dried for one week under normal ambient air temperatures in the laboratory. After one week of drying, samples A and B were first ground to a -10 mesh size using a ceramic plated, direct drive pulverizer. A second grinding was done to -60 mesh size. All material was screened to pass the 60 mesh size. The two samples were then placed in separate, one gallon plastic containers and covered. The processing closely resembles our standard method of sample preparation for all spoil and overburden material received for standard Wyoming overburden characterization. The one difference is that grinding samples to -60 mesh is not normally done for selenium analysis. This was done to help blend the material for a homogenous test sample.

Once samples were prepared, laboratory personnel were to complete a hot water selenium extraction and an AB-DTPA extraction once a week. The analysis was to be done with other routine analysis. On average, 200-400 selenium samples are extracted and analyzed weekly. The weighing and extraction were completed by a variety of lab personnel. Pretreatment of extracts and hydride generation by AA was completed by one person over a six month analysis period. This was the same lab procedure used for all other selenium samples done in our lab over the same six month period.

EXTRACTION METHODS

Hot Water Extractions

A 25.0 gram sub-sample of each material is weighed into a small measuring cup on a scale and then transferred through a funnel into 100 ml plastic bottles. Fifty milliliters of 0.1% calcium chloride is then autopipeted into the bottles with the samples. Samples are heated without boiling in the microwave for 6-7 minutes. After heating, the samples are allowed to steam for 30 minutes. Next, they are shaken slightly by hand and filtered through a #2 Whatman filter paper.

AB-DTPA Extractions

Twenty five grams of both the A&B samples are also weighed on the scale in a small measuring cup. The samples are transferred through a funnel into 100 ml bottles. AB-DTPA extracting solution is then made fresh by combining ammonium bicarbonate (NH_4HCO_3), diethylenetriaminepenataacetic acid (DTPA), and ammonium hydroxide (NH_4OH). The pH is adjusted to 7.6 by adding concentrated hydrochloric acid or ammonium hydroxide. Fifty mls of the AB-DTPA extracting solution is then autopipeted into the bottles with the samples. The samples are placed in the shaker for 15 minutes. Then they are filtered through #2 Whatman filters.

PREPARATION OF EXTRACTS FOR ANALYSIS

Prepping Samples

With an Oxford pipette, 3 mls of the filtered samples are pipetted into clean large test tubes. Between each sample, the pipet tip is rinsed with nano-pure water. After every 10 samples, either a duplicate or spike (0.0500 ppm selenium) is prepared. Once the samples are all pipetted into the tubes, 1 ml of 30% hydrogen peroxide is added with an eppendorf repeater pipet. To the identified spikes, 3 ml of 0.0500 standard is added. Eleven mls of nano-pure water is then added to the samples and 8 mls of nano is added to the spikes. Final volume of standards and spikes is 15 mls.

Prepping Standards

Eight test tubes are used for each standard and for the Spex-9 known control (QC) sample. Sixteen test tubes are used for the blank. Analyst then pipets 3 mls each of standard, QC, or blank into the tubes. 1 ml of 30% hydrogen peroxide and 11 mls of nano-pure water are then added to the standards, QC, and blanks. Final volume of standards and blanks is 15 mls.

Heating

The racks of samples and standards are placed in pans of tap water heated to 180°F for 20 minutes after the 30% hydrogen peroxide is added. The samples are then removed and 10.0 mls of concentrated hydrochloric acid is added to each test tube. Caution must be taken when adding acid to warm samples with hydrogen peroxide in them. Foaming and spillover may occur, in which case the samples must be prepared again. After the acid has been added, samples are again heated for exactly 20 minutes in the 180°F hot water bath. This 20 minutes is extremely important for reduction of selenium valence states and breakdown of organic selenium compounds. Samples are removed from the water bath and allowed to sit, covered, overnight to be analyzed the next morning.

INSTRUMENT SET UP

Preparing to run

The following morning, the Varian AA Spec-20 is turned on. The instrument parameters are set with lamp current at MA=7, delay rinse time=28.0 sec., read time of analysis with 3 replicates of the read out time-2.0 sec, background correction=off. The Spec-20 is then optimized by adjusting the wavelength, lamp, and absorption cell. The standards used to program a linear regression are: 0.0100, 0.0200, 0.0500, 0.1000, and 0.1500 ppm.

While the lamp is warming up, the reagents are prepared. The first reagent is sodium borohydride ($NaBH^4$), which is made by dissolving 2.5 grams of sodium hydroxide in nano-pure water in a 500ml volumetric flask. Once it is dissolved, 3.0 grams of sodium borohydride are added and dissolved. The solution is brought up to volume (500 mls) and poured into the designated container. The second reagent, 1+1 hydrochloric acid, is made by placing 250 mls of nano-pure water and 250 mls of concentrated hydrochloric acid in a 500 ml volumetric. It is mixed very well and poured into its container.

All test tubes of each standard and blank are mixed together in 250 ml bottles. The QC remains in their identified test tubes so that each time one is run, the value can be plotted to determine the precision and accuracy of the machine. The bottles are placed in order in front of the Spec-20.

The VGA aspirating tubes are placed into reagents and the pump tubes are placed around the pump. The nitrogen and Varian Hydride Generator (VGA) are then turned on.

The acetylene is turned on, the gas pressure is checked and the flame is ignited. Before starting to calibrate, the mixing chamber is checked to make sure the reagents are producing bubbles.

ANALYSIS OF SAMPLES

The sample tube is placed into the blank to begin the calibration. The blank must be run a couple of times before it gets to the baseline. Once a 0 absorbance (± 0.001) is obtained, the standards, 0.010, 0.0200, 0.0500, 0.1000, and 0.1500, are run. The "r" values for the absorbance readings from the AA need to be greater than .9950. After the calibration, a blank, a QC, a .0200 standard, and a .1000 standard are run before beginning to analyze samples. This insures the proper instrument response.

During the run, the A&B samples are usually analyzed toward the end of the soil samples. Every 30 or 40 soil samples a blank and QC sample or a blank, 0.0200 and 0.1000 standards are run. For soil, the calibration verification standard is usually run rather than the QC sample. Once all the samples have been analyzed, a blank is run. The machine is then shutdown by turning off the lamp energy and turning off the power.

DISCUSSION

For the study in question, laboratory personnel recorded all results of the tests over a 23 week period. Our purpose was to evaluate the analysis as if it were a normal test sample, and not a QC or known control sample. Therefore, looking at the data, a person could say this is the normal variability to be expected for selenium analysis. In addition, a comparison of the two methods of extraction could be evaluated. Table 1 summarizes the analysis for the 23 weeks.

Table 2 summarizes the sample statistics comparing the hot water and AB-DTPA extractions for sample A and sample B. The standard deviation of 0.02 indicates that both tests are very precise. A t statistic analysis was computed using the hypothesis that both extraction methods will result in the same value. The computed t statistic of (-)11.18 for sample A and (-)9.88 for sample B compared to a tabulated $t_{.025}$ of 2.017 shows a rejection of the hypothesis. The hot water and AB-DTPA analysis will not result in the same value for either of these two overburden samples.

In reviewing the analysis, it appears that both the hot water and AB-DTPA analysis have, over time, increased in value. A common comment to our laboratory from clients has been "Every time I send in a sample or use a different lab, I get a different number". The greatest amount of variability is most likely due to different laboratory procedures and methods of analysis. Our laboratory has been involved with several inter-lab selenium studies over the years and these procedures have proven to significantly influence results. However, we feel that selenium definitely increases over time and we will continue to evaluate samples A and B for another six months.

SUMMARY

The test data of the hot water and AB-DTPA extraction indicate precise selenium results. The fact that the samples were ground to a -60 mesh size may have influenced statistical data. The accuracy of the data is difficult to compare because a certified control sample is not available at this time. The t statistic analysis indicates a difference between the hot water and AB-DTPA extraction for these two samples with the AB-DTPA producing higher values than hot water extraction. Lastly, we will continue to analyze these two

TABLE 1
Time Study Selenium Analysis on Overburden Material

Date	Sample ID	Hot Water Se ppm	AB-DTPA Se ppm
7/2/92	A	0.170	0.242
	B	0.166	0.216
7/7/92	A	0.148	0.238
	B	0.148	0.220
7/14/92	A	0.200	0.260
	B	0.190	0.240
7/21/92	A	0.166	0.218
	B	0.162	0.192
7/29/92	A	0.194	0.200
	B	0.182	0.214
8/3/92	A	0.178	0.250
	B	0.174	0.242
8/13/92	A	0.218	0.266
	B	0.208	0.206
8/18/92	A	0.202	0.246
	B	0.200	0.246
8/25/92	A	0.208	0.250
	B	0.200	0.232
9/1/92	A	0.186	0.266
	B	0.182	0.238
9/8/92	A	0.188	0.268
	B	0.182	0.230
9/15/92	A	0.202	0.256
	B	0.200	0.244
9/22/92	A	0.186	0.252
	B	0.168	0.230
9/29/92	A	0.200	0.248
	B	0.192	0.236
10/8/92	A	0.186	0.240
	B	0.180	0.252
10/13/92	A	0.196	0.262
	B	0.200	0.244
10/20/92	A	0.188	0.272
	B	0.170	0.252
10/27/92	A	0.230	0.276
	B	0.224	0.264
11/3/92	A	0.184	0.270
	B	0.176	0.254
11/12/92	A	0.164	0.246
	B	0.182	0.236
11/18/92	A	0.202	0.262
	B	0.194	0.248
11/23/92	A	0.206	0.250
	B	0.198	0.246
12/2/92	A	0.214	0.260
	B	0.202	0.244

TABLE 2
Two Sample Analysis Results

Sample Statistics	**Hot Water A**	**AB-DTPA A**	**Hot Water B**	**AB-DTPA B**
Number of Obs.	23	23	23	23
Average	0.19	0.25	0.19	0.23
Variance	0.0003	0.0003	0.0002	0.0002
Standard Deviation	0.02	0.02	0.02	0.02
Median	0.19	0.25	0.18	0.24

Sample A:
Null Hypothesis:
Difference equals 0 vs. the alternative hypothesis, difference not equal to 0.

at Alpha = 0.05
Computed t statistic = (-)11.18
Tabulated $t_{.025}$ statistic = 2.017
So reject Hypothesis H0.

Sample B:
Null Hypothesis:
Difference equals 0 vs. the alternative hypothesis, difference not equal to 0.

at Alpha = 0.05
Computed t statistic = (-)9.88
Tabulated $t_{.025}$ statistic = 2.017
So reject Hypothesis H0.

samples to see if some variability of selenium analysis may be time sensitive.

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SELENIUM OR SULFUR?

A Comparison of Toxic Effects in Mammals on Western Rangelands

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ABSTRACT

The potential mobilization of selenium by surface mining has been recognized by regulations limiting its concentration in overburden for several years. While there is little question that selenium is very toxic, recent evidence suggests that much of what has been attributed to selenium in the past is, in fact, due to the much more ubiquitous element sulfur. This paper reviews of the toxic effects of these chemically very similar elements in western range mammals.

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INTRODUCTION

Selenium (Se) and sulfur (S) tend to occur together in much of the western Great Plains of North America. Both are group VIA elements which can exist in a variety of oxidation states. Both are essential for life. Both are potentially toxic.

The reduced form of either element (eg. sulfide and selenide) is relatively insoluble in water and thus relatively immobile in the geosphere and thus unavailable to livestock and wildlife. However, as a result of disturbances by activities such as mining, either element may become oxidized to a readily water soluble form which has far greater potential for uptake by animals. This paper will attempt to summarize and differentiate the toxic effects of these elements in wildlife and livestock.

KNOWN TOXIC EFFECTS OF SELENIUM

Acute Selenosis

Acute poisoning by Se most commonly results from accidental overexposure to feed supplements or pharmaceutical preparations (Morrow 1968; Wilson et al., 1983; Harrison et al., 1983; Casteel et al., 1985; Krieger et al., 1986; Janke, 1989) although at least one episode of possible phytogenic acute selenosis has been reported (James, 1982). Although clinical signs vary somewhat between species, they are usually referable to gastrointestinal, myocardial and renal damage. All species exhibit lassitude, inappetence and generalized weakness and tend to assume a stance characteristic of abdominal pain with abdomen tucked and head lowered. Labored respiration (possibly with bloody sputum) and muddy mucus membranes are seen in most species. Shock, as evidenced by cold extremities, rapid weak pulse and prolonged capillary refill is a consistent finding in experimental intoxication as well as case reports. Death is usually attributed to respiratory and or circulatory failure (MacDonald et al., 1981; Blodgett and Bevill, 1987; Ahmed et al., 1990; Smyth et al., 1990).

Pathologic changes reported after acute selenium poisoning also vary somewhat between reports, but usually include hemorrhagic enteritis, possibly with ulcerations, cardiac damage and congestion and focal hemorrhages in the lungs. There are variable degrees of hemorrhage in and on the surface of the myocardium. Liver and kidney are often congested and softened. Histopathologically, these gross changes are accompanied by hydropic degeneration, focal necrosis and hemorrhage in heart, liver, and kidney (Morrow, 1968; MacDonald et al., 1981; Blodgett and Bevill, 1987; Ahmed et al., 1990; Smyth et al., 1990).

Subacute selenosis

Polio*myelo*malacia and *posterior* paralysis has been reported as a sequela in swine, which survived acute intoxication or which were experimentally fed subacutely-toxic doses of inorganic Se salts (Harrison et al., 1983; Wilson et al., 1982; Wilson et al., 1983; Casteel et al., 1985). After approximately 2 weeks on elevated dietary Se, pigs developed hindlimb paralysis or in some cases quadriplegia. Although they were unable to walk, affected pigs remained bright and alert and would eat if food and water were placed in front of them. At *post mortem* examination, bilaterally symmetric, light yellow or gray foci were observed in ventral horn gray matter of cervical and lumbar enlargements with milder degenerative lesions in the brain stem. Histopathologically these lesions consisted of necrosis and cavitation with little or no inflammatory response (Wilson et al., 1983; Harrison et al., 1983). Acute myocardial necrosis was seen in some but not all pigs. Hair loss and cracked hooves were seen in some but not all survivors. Similar signs and lesions have been reported from swine experimentally fed *Astragalus bisulcatus* (Baker et al., 1989). Aside from one questionable report in a llama (Farrar and Johnson, 1992) this condition, to the best of our knowledge has not been identified in species other than swine.

Chronic selenosis

Chronic selenosis in mammals has historically been divided into conditions described as "blind staggers" and "alkali disease". While there is serious doubt as to the etiology of "blind staggers" (see below), hoof and hair lesions similar to those reported for alkali disease have been produced experimentally in cattle, horses and swine (Miller and Williams, 1940; Olson and Embry, 1973; Baker et al, 1989). Alkali disease is characterized by hair loss, especially of the mane and tail in horses, and hoof damage beginning at the coronary band, one or more months after introduction to seleniferous pasture. Older references also report ill-thrift, anemia, arthritis and wasting; however, in our experience, the latter effects do *not* occur when affected animals receive adequate supplies of food and water. The latter observation supports the contention that only the epithelial effects (ie. hoof and hair loss) are directly related to chronic selenosis and that the spectrum of maladies attributed to "alkali disease" were, in fact, a result of the inability of affected animals to get to food and water under range conditions.

Histopathological lesions described for chronic selenosis in the older literature comprise hepatic lipidosis, fibrosis and cirrhosis, nephrosis and myocardial fibrosis (Draize and Beath, 1935; Miller and Williams, 1940; Rosenfeld and Beath, 1946). While not very specific, these findings are the logical sequelae of the sort of lesions seen in acute and subacute selenium intoxication. Nonetheless, Olson and Embry (1973) indicated that in one of five heifers which developed hoof lesions after 190 days on 15 ppm dietary Se "no gross lesions of the type often associated with "alkali disease" were noted." Nor have we observed clinicopathological changes indicative of liver or kidney damage in naturally occurring cases of apparent alkali disease in horses in Wyoming (Raisbeck et al., 1992). Thus, it would appear that systemic damage is either not necessary for the epithelial lesions of alkali disease, or that such damage may resolve itself before the onset of hoof and hair lesions. Conversely, chronic heart, liver and kidney damage may occur without the characteristic damage to hooves and hair.

The target tissue in chronic selenosis of sheep, which reportedly do not develop alkali disease type lesions is cardiac musculature. Se intoxicated sheep show few clnical signs until a few hours to several days before death. Experimental studies (Glenn et al, 1964; Smyth et al., 1990) document subacute myocardial necrosis. The pattern of myocardial necrosis and fibrosis, selectively involving left ventricle and interventricular septum, is remarkably similar to that of nutritional myocardiopathy due to vitamin E/Se deficiency. The sifnificance of myocardial disease in chronic selenosis of cattle (Rosenfeld and Beath, 1946) and horses (Miller and Williams, 1940) remains to be established.

TOXIC EFFECTS OF SULFUR

While industrial safety aspects of sulfur compounds have been studied extensively, only limited information is available regarding the effects on animals of sulfur contamination of feedstuffs and drinking water. The major terrestrial source of sulfur is sulfide-containing minerals which are converted to sulfate by weathering. Plants, soil microbes and rumen microflora convert inorganic sulfur (eg. sulfate) to organic sulfur compounds, including the amino acids methionine, cysteine and cystine. Monogastric animals on the other hand have few if any assimilator bacteria to convert inorganic sulfur to amino acids and thus must rely upon exogenous sources sulfur containing amino acids. Both ruminants and monogastrics are host to bacteria capable of reducing dietary inorganic sulfur to hydrogen sulfide (H_2S) in the gastrointestinal tract (NAS, 1980).

The toxicity of sulfur depends upon the chemical form and route of administration. The most hazardous form of S toxicity, H_2S inhalation, is not usually a problem in range animals, since the normal routes of sulfur exposure are vegetation and water.

In monogastrics moderately high drinking water concentrations of sulfate salts cause diarrhea and dehydration. Excessive dietary S-containing amino acids (eg. methionine) have been reported to result in growth depression in rats, chicks and swine (NAS, 1980). Nevertheless, the causative role of S in these syndromes is usually difficult to pin down under field conditions because animals may become adapted to high S diets and because of the multiplicity of other etiologies which cause similar signs.

In ruminants, the situation is somewhat more complex. At nutritionally adequate dietary concentrations most inorganic forms of S are incorporated into S-amino acids by rumen microflora (NAS, 1980). At higher concentrations such compounds are progressively reduced to sulfides, eg. H_2S (Lewis, 1954). Excess dietary S may alter ruminal ecology. Dietary sulfate may also complex with copper (Cu) and molybdenum, increasing Cu excretion and decreasing Cu bioavailability.

In its simplest form, acute S toxicity in ruminants results from short term exposure to relatively large doses (ie. g/kg). The most common source of such exposure is the use of S as a parasiticide (Raisbeck et al., unpublished). The mechanism of action is essentially H_2S intoxication and thus results in sudden death with few or no premonitory signs and only nonspecific post mortem lesions. Slightly lesser dosages result in muscular twitching, restlessness, diarrhea, dyspnea (difficult breathing) and recumbency prior to death. Some animals may become blind. The condition runs its course within 24 hr to (at most) a few days. Post mortem lesions include a strong "rotten egg" odor to gastrointestinal contents, severe enteritis, peritoneal effusion, darkened kidneys and generalized petechial hemorrhages (NAS, 1980). In an unusual case of slurry gas poisoning, lesions suggestive of cerebrocortical necrosis or polioencephalomalacia (PEM) were reported although the authors did not suggest this association (Dahme et al., 1983).

The earliest signs of chronic sulfur toxicosis in ruminants are related to gastrointestinal upset. Excessive drinking water sulfate concentrations usually produce loose feces and/or frank diarrhea within a few days. This condition may resolve itself as animals adapt, or may progress to include anorexia, rumen atony, constipation and dehydration. Mortality is usually very low; however, economic losses from decreased reproductive efficiency and weight gain can be significant.

As a practical matter sulfate-induced copper deficiency usually occurs in cattle maintained on diets which are low or merely adequate in Cu. Excessive Mo will also exacerbate the condition. Unfortunately, pasture grasses in most of the Mountain West are often marginal in Cu. Overt copper deficiency appears as hair depigmentation, diarrhea, anemia, osteoporosis and arthritis. Cardiovascular elastin defects may result in aortic rupture or "falling disease". Such extreme cases are fortunately rather rare and decreased gain, immunodeficiency and infertility account for most losses (Thompson and Buck, 1992).

Sulfur-induced polioencephalomalacia (PEM)

The most recently discovered effect of excessive sulfur intake in ruminants is PEM. Clinical manifestations of PEM include sudden onset, blindness, incoordination, circling and head pressing. Severely affected animals may exhibit convulsions and opisthotonos. Morbidity in affected herds varies from less than 1% to 50%, mortality approaches 100% in untreated animals (Raisbeck, 1981).

PEM was first recognized as a distinct pathologic entity in Colorado range cattle by Jensen et al. (1956) and later associated with thiamine deficiency (Davies et al., 1965). Since that time various other possible etiologies have been identified. Dietary sulfur was incriminated as a possible etiology only recently (Raisbeck, 1981; Sadler et al., 1983; Gooteratne et al., 1989; Sager et al., 1990; Gould et al., 1991).

The pathogenesis of S-induced PEM and "safe" dietary concentrations of S are, as yet, ill-defined. It is known that sulfite (a ruminal metabolite of sulfate) destroys thiamine in the gastrointestinal tract; thus it was originally suggested that the condition merely represented a novel form of thiamine deficiency (Raisbeck, 1981). More recent evidence, however, suggests a subacute to chronic, direct toxic effect of S metabolites, most probably H_2S in the brain (Gooteratne et al., 1989; Gould et al, 1991). The threshold concentration of dietary S necessary to cause PEM apparently varies with other dietary factors; at present most investigators suggest keeping dietary (ie. water and forage) sulfur less than 3000 - 5000 ppm. It should be stress, however, that this recommendation will likely change as more information becomes available.

BLIND STAGGERS: SELENIUM OR SULFUR?

As mentioned previously, the research which eventually demonstrated the toxic nature of seleniferous vegetation and its causative role in acute selenosis and alkali disease was undertaken at Agricultural Experiment Stations in the western US during the early 1900's. However, in addition to these conditions, the research group headed by O. A. Beath at the University of Wyoming claimed that seleniferous vegetation was responsible for a condition known among laymen as "blind staggers".

"Blind staggers" was first recognized by ranchers in the western Great Plains near the turn of the century. The condition seemed to be associated with (among other things) the same alkali soils and waters that gave "alkali disease" its name. Only ruminants were affected. Clinical signs common to most field episodes included wandering in circles and attempting to walk through obstacles. When confronted with a obstacle affected animals refused to backup and would continue leaning into it with their head. There was a notable forelimb ataxia. Anorexia was eventually followed by paralysis, occasionally convulsions and death (Trelease and Beath, 1949; Rosenfeld and Beath, 1964). The condition often occurred after cattle had been shipped to feedlots and were being fattened for market (Trelease and Beath, 1949).

There are several reasons for questioning the existence of "blind staggers" as a selenium-induced disease:

The original association between "blind staggers" and selenium was apparently based upon the identification of selenium accumulator plants in the state. As noted in Rosenfeld and Beath (1964), "The ability of widely distributed plants of *Astragalus* to accumulate several thousand parts per million selenium explained the ... hitherto unknown cause of blind staggers." The obvious discrepancy that "blind staggers" occurred in cattle that were not exposed to these plants was never explained.

"Blind staggers" has never reproduced by feeding selenium or selenium compounds. Beath's group reportedly produced neurologic signs in cattle and sheep by feeding seleniferous weeds for prolonged periods, but detailed reports of these experiments were never published. One experiment station report mentions "brain edema" (Rosenfeld and Beath, 1946) and another describes "degeneration" of "certain areas of the brain" (Beath et al., 1953). Unfortunately, although the clinical signs reported were those of a central nervous system disease, histopathological examination of the brain does not appear to have been done.

At the time of the original reports, PEM had not yet been recognized. Nonetheless, the similarity in reported signs is striking. Many of the ranches in southern Wyoming which supplied field cases of "blind staggers" during the 1920's and 1930's still experience the same problem on the same pastures. However, most of the affected animals have lesions of PEM, and the onset of clinical signs is usually associated with high sulfate waters. Tissue Se concentrations may or may not be elevated above textbook "normal" ranges, but even then they are not greater than what is commonly seen in animals from these areas.

Today, thiaminase-induced PEM is a well-recognized possible sequela of the change from pasture to high concentrate fattening diets in feedlots and precautions are taken to avoid it. However, prior to the late 1960's, this fact wasn't recognized. Might it be that the delayed "blind staggers" described in cattle sent to feedlots by Beath et al. was in fact PEM?

Details of the feeding trials with selenium accumulating plants at Wyoming are scanty at best. Beath maintained that there is little toxic material other than Se in the species of *Astragalus* he fed to cattle and sheep (Rosenfeld and Beath, 1964); however, other investigators have isolated swainsonine, the causative agent of the CNS disease locoism from this species (Molyneaux et al, 1985). It is likely that the neurological signs produced by experimentally feeding selenium accumulators was in fact primarily locoism, complicated by selenium-induced damage to liver, kidney and heart and severe malnutrition (Van Kampen and James, 1978).

SUMMARY

Both S and Se are essential elements for wildlife and livestock. Both are potentially hazardous, if dietary concentrations become high enough. The availability of either to grazing animals may, in theory, be enhanced by natural or human activities which expose reduced forms of these elements to oxidation. Se, in relatively massive doses may cause sudden death. Sustained exposure to smaller doses may damage heart, liver and kidneys and, in some instances, cause hair loss and hoof deformities, especially in horses. S, in large doses, may also cause sudden death. Chronic exposure to lower concentrations may cause ill-thrift, diarrhea, and, in ruminants, PEM. Although the toxicity of S is less than that of Se, S occurs at much greater concentrations in the environment. The incidence of the type of diseases in livestock *proven* to result from S toxicity appears to be much greater than that of diseases *proven* to result from Se toxicity. However, the contribution of either element to subclinical conditions such as immunosuppression and infertility remains to be identified under natural conditions.

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Selenium in Aquatic Birds Nesting in the Kendrick Reclamation Project, Natrona County, Wyoming: Apparent Impacts from Irrigation Drainwater

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ABSTRACT

Studies of nesting aquatic birds were conducted in 1988-89 by the U.S. Fish and Wildlife Service (Service) to determine if irrigation drainage has caused or has the potential to cause harmful effects to migratory aquatic birds. Elevated selenium concentrations were found in the aquatic food chain at levels suspected of causing adverse effects to birds (> 3 μg/g to 166 μg/g dry weight). Embryo mortality and deformities found in American avocets (Recurvirostra americana); Canada geese (Branta canadensis); and eared grebes (Podiceps nigricollis) may be linked to the selenium-contaminated food chain as these breeding birds probably feed almost exclusively in the Kendrick Reclamation Project. Mean egg selenium in American avocets, eared grebes, dabbler ducks (Anas spp.) and Wilson's phalaropes (Phalaropus tricolor) were 82.7, 75.1, 13.1 and 11.7 μg/g dry weight, respectively. Concentrations above 8 μg/g dry weight are associated with impaired hatchability and concentrations above 13 μg/g dry weight are associated with teratogenic populations of aquatic birds in western and northern plains states (Skorupa and Ohlendorf 1991). Juvenile Canada geese and eared grebes and adult American avocets had selenium at concentrations suspected of causing adverse reproductive effects or toxicosis (> 30 μg/g dry weight). Elevated selenium concentrations in fish from Kendrick Project wetlands and the adjacent North Platte River may pose a bioaccumulation risk to fish-eating birds.

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INTRODUCTION

This study was conducted as part of the U.S. Department of Interior's National Irrigation Water Quality Program in an effort to address water quality problems stemming from irrigation drainwater. The study was part of an interbureau investigation involving the U.S. Geological Survey (Survey) and the U.S. Fish and Wildlife Service (Service)(See et al. 1992). Elevated selenium concentrations in sediment, water and biota from the Kendrick Reclamation Project (Kendrick) were first documented during a reconnaissance investigation conducted in 1986-87 by the Survey and the Service (Peterson et al. 1988). The Kendrick Reclamation Project is located in Natrona County in Central Wyoming. Approximately 24,000 acres of alfalfa and improved pasture are irrigated at Kendrick.

The objectives of the biota component of the drainwater study were to:

1) determine bird use in wetlands within the Kendrick area;

2) determine selenium concentrations in the food chain;

3) assess the effects of selenium in birds and fish; and

4) define the major pathways for selenium.

Biota study efforts focused on four major wetlands within the Kendrick area: Rasmus Lee Lake (730 acres); Goose Lake (100 acres); Illco Pond (2 acres); and Thirty-three Mile Reservoir (10 acres). Soda Lake, a closed basin immediately north of Casper, and an oxbow pond along the North Platte River were used as reference sites.

Appreciation is extended to the Wyoming Game and Fish Department Casper District Office, to Tony Morton, U.S. Bureau of Reclamation, and Joni Armstrong for their assistance with the field studies.

METHODS

Biota were collected during 1988 and 1989. Pondweed (Potamogeton vaginatus) was collected by hand at the four wetland sites and two reference sites. Aquatic invertebrates were collected from the four wetland sites and the oxbow pond using light traps as described by Espinosa and Clark (1972). Aquatic bird nest surveys were conducted from April through July. Addled bird eggs were collected, dissected and examined for deformities. Adult avocets, dabbler ducks and eared grebes and juvenile pre-fledged Canada geese and eared grebes were collected with a shotgun and steel shot, dissected and their livers removed. Bird carcasses found at Kendrick were recovered and their livers were analyzed for selenium. Biota samples were placed in chemically-clean glass jars, frozen and submitted for trace element analyses. Bird surveys were conducted weekly from April through October at the four major wetlands sites and the oxbow pond.

RESULTS

Rasmus Lee and Goose lakes are closed basins. Surface runoff and seepage from irrigation distribution canals contribute water to these wetlands. Of the four major wetlands, Rasmus Lee and Goose lakes have the highest selenium concentrations in water due to evaporative concentration, 38 and 54 μg/l, respectively (See et al. 1992). Selenium in water from tributaries draining Kendrick were higher immediately downstream of the irrigation area than upstream. This indicates that irrigation is influencing selenium transport at Kendrick. Median selenium concentrations in water upstream of Kendrick were below 1 μg/l; whereas, concentrations downstream ranged from 68 to 200 μg/l (See et al. 1992). Waterborne selenium concentrations greater than 20 μg/l pose a high biological risk for aquatic bird species. Impaired reproduction and embryotoxicity has been documented in wetlands with waterborne selenium concentrations greater than 20 μg/l (Skorupa and Ohlendorf 1991).

Selenium concentrations were elevated in muscle tissue from rainbow trout (Onchyrhynchus mykiss) collected from North Platte River reaches receiving irrigation return flows from Kendrick. Mean selenium concentrations ranged from 10.9 μg/g to 12.6 μg/g dry weight. The increase in selenium downstream suggests cumulative impacts due to selenium loading from the tributaries draining Kendrick irrigation project. Selenium concentrations greater than 8 μg/g dry weight in fish muscle tissue may cause reproductive impairment (Lemly and Smith 1987). Fish inhabiting Thirty-three Mile Reservoir and Illco Pond had whole-body selenium concentrations ranging from 12 to 41 μg/g dry weight. Selenium concentrations greater than 12 μg/g can cause reproductive impairment in fish (Lemly and Smith 1987).

Selenium concentrations in fish from the North Platte River, Thirty-three Mile Reservoir and Illco Pond may pose a biological risk to fish-eating birds. Selenium concentrations in livers from three juvenile pre-fledged double crested cormorants (Phalacrocorax auritus) collected from Soda Lake in July 1992 suggest that this element is bioaccumulating in fish-eating birds. Two of the three cormorants had selenium concentrations of 14.7 and 39.5 μg/g dry weight. As a comparison, double-crested cormorants from American Falls Reservoir in Idaho had selenium concentrations of 4.3 and 5.5 μg/g dry weight.

Selenium in pondweed from Rasmus Lee Lake, Goose Lake and Illco Pond exceeded the 3 μg/g dietary threshold for aquatic birds, 38 μg/g, 14 μg/g, and 4.4 μg/g dry weight, respectively. Concentrations greater than 3 μg/g pose a biological risk in terms of bioaccumulation and impaired reproduction (Lemly and Smith 1987). Pondweed from Thirty-three Mile Reservoir and the two reference sites had selenium concentrations below 3 μg/g.

Selenium in aquatic invertebrates from the four major wetlands and the oxbow pond also exceeded the 3 μg/g dietary threshold (Table 1).

Table 1. Mean selenium concentrations (μg/g dry weight) in aquatic invertebrates from Kendrick area wetlands.
(n) number of samples

Site	Odonates	Chironomids	Waterboatmen	Amphipods
Rasmus Lee Lake	(2) 94.4	(3) 158	(2) 99.1	--
Goose Lake	(1) 46.7	--	--	(9) 44.8
33-Mile Reservoir	--	--	(4) 14.2	--
Illco Pond	--	--	(4) 29.7	--
Oxbow Pond	(1) 13.6	(4) 10.9	(2) 15.9	--

Selenium in pondweed and aquatic invertebrates at Kendrick is bioaccumulating in aquatic birds and is posing a biological risk. Selenium in livers from aquatic birds collected at Kendrick exceeded the 10 μg/g concentration considered background and the 30 μg/g level associated with impaired reproduction and mortality (Skorupa and Ohlendorf 1991) Table 2.

Table 2. Mean selenium concentrations (μg/g dry weight) in livers from birds collected at the Kendrick irrigation project.

Species	Number of Samples	Selenium
Dabbler Ducks (adult)	12	35.1
Canada Goose (juvenile)	10	35.6
American Avocet (adult)	4	75.9
Eared Grebe (adult)	4	74.2
Eared Grebe (juvenile)	5	77.7

Selenium in livers from bird carcasses recovered at Kendrick were also elevated in all but three Canada goose carcasses (Table 3).

Table 3. Selenium concentrations (μg/g dry weight) in livers from aquatic bird carcasses recovered at Kendrick.

Species	Number of Samples	Selenium
Canada Goose (juvenile)	3	3.7
Eared Grebe (adult)	2	97.5
Eared Grebe (juvenile)	1	81.3
American Avocet (adult)	1	54.0
Lesser Scaup (adult)	1	79.7
Wilson's Phalarope (adult)	1	34.5
Green-winged Teal (adult)	1	30.7
Ruddy Duck	1	93.0
American Coot	4	70.9

Selenium in aquatic bird eggs exceeded the 3 μg/g concentration considered background (Skorupa and Ohlendorf 1991)(Table 4). American avocet and eared grebe eggs exceeded the upper threshold range of 37 μg/g for mean egg selenium associated with impaired egg hatchability and elevated incidence of embryo teratogenesis (Skorupa and Ohlendorf 1991).

Table 4. Mean egg selenium (μg/g dry weight) in aquatic bird eggs from Kendrick.

Species	Number of Samples	Selenium
Canada Goose	115	7.5
American Avocet	102	82.7
Eared Grebe	151	75.1
Dabbler Ducks	6	13.1
Wilson's Phalarope	6	11.7

Dabbler duck eggs slightly exceeded the lower threshold range of 13 μg/g dry weight for mean egg selenium associated with impaired reproduction and embryo deformity (Skorupa and Ohlendorf 1991).

Although Canada goose eggs had the lowest selenium concentrations of all eggs collected at Kendrick, mean egg selenium exceeded background levels. Impaired reproduction was observed in Canada geese with egg hatchability ranging from 45 to 47 percent. Egg hatchability in uncontaminated populations of Canada geese should approach 90 percent (Klopman 1958). Reduced egg hatchability was also observed in American avocets, 51 percent. Hatching success should range from 79 to 90 percent in uncontaminated avocet populations (Gibson 1971 and Sidle and Arnold 1982). Reliable estimates of nesting success in eared grebes, dabbler ducks and Wilson's phalaropes could not be made due to logistics.

Deformities associated with selenium toxicosis were observed in Canada goose, American avocet and eared grebe embryos (Table 5).

Table 5. Number of deformities observed in aquatic bird embryos at Kendrick.

Deformity	Canada Goose n=48	American Avocet n=39	Eared Grebe n=50
Micropthalmia	2	2	4
Ectromelia	--	2	--
Hydrocephaly	--	3	4
Crossed bill	--	5	--
Ectrodactyly	--	8	--
Total (Percent) Embryos	2 (15)	9 (24)	5 (10)

American avocet embryos had the highest incidence of deformities. The incidence of major external deformities in uncontaminated wild bird populations is normally less than one percent (Hill and Hoffman 1984). At Kendrick, the occurrence of embryo deformities ranged from 10 to 24 percent.

SUMMARY

Selenium contamination and bioaccumulation pose a significant biological risk to aquatic migratory birds using the Kendrick wetlands. Approximately 42 species of aquatic birds use Kendrick area wetlands. A maximum of 6,000 to 7,000 birds were observed during the fall migration at Kendrick. The wetlands at Kendrick serve to concentrate aquatic migratory birds due to the semi-arid nature of the area. The selenium-contaminated food chain poses a high biological risk not only to breeding birds but also to migratory aquatic birds stopping over, resting and feeding at Kendrick. Aquatic birds can accumulate selenium to adverse levels in as little as seven days; however, it takes longer for birds to purge the selenium in a non-contaminated environment (Heinz et al. 1990).

The U.S. Bureau of Reclamation, in cooperation with the Survey and Service, is currently conducting a remedial planning study to correct the selenium contamination problem at Kendrick.

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SELENIUM AND MINING IN THE POWDER RIVER BASIN[1]

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ABSTRACT

Selenium in soils, vegetation, and water has become an important issue in Wyoming. This topic has far-reaching effects on surface mining, some of which are now being felt. As a result of regulatory actions initiated in the mid 1980's, the Land Quality Division of the Wyoming Department of Environmental Quality, the Wyoming Mining Association, and the University of Wyoming formed interactive research committees to address the issue of selenium and mining. The objectives of the committees are: to establish current and detailed selenium sampling and analytical procedures; to identify selenium levels in the pre- and postmining environments of the Powder River Basin; to develop predictive relationships between selenium in the environment and organisms; and to identify appropriate suitability levels for selenium in postmining backfill.

These objectives are being met by a three-phase research project for soil, overburden, vegetation, and wildlife. Phase I consisted of analyzing vegetation selenium levels on both native and reclaimed lands in 1991 and 1992. Phase II, which is currently being conducted, involves the analyses of selenium in overburden, soils, and backfill. The information obtained in Phase II will be used to evaluate the correlation of plant selenium levels with selenium concentrations in overburden, soil, and backfill. Phase III will attempt to identify the effect of selenium on target organisms in 1994. Selection of research sites for Phases II and III will be based on the range of selenium values encountered in Phase I vegetation sampling.

Phase I included: identifying sampling sites, recording several environmental variables at each site, conducting a vegetation survey, sampling the vegetation by life-forms, and analyzing the selenium in the sampled vegetation. Preliminary results of Phase I will be presented here.

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INTRODUCTION

Selenium, an element widely distributed through the earths crust, tends to be found in sedimentary geologic material and formations (Case and Cannia, 1988). It is commonly found in varying degrees throughout the sedimentary formations of Wyoming. The Powder River Basin, the site of large scale surface coal mining activity, contains such sedimentary formations.

Selenium is an essential micronutrient when consumed in trace amounts, yet when consumed in quantities exceeding particular threshold limits, it becomes toxic. Fisher et al. (1989) identified two areas of concern regarding selenium and surface coal mine reclamation:

- the exposure of seleniferous materials by mining such that selenium uptake by plants could result in selenium toxicity to foraging animals; and
- the quality of both surface and ground water that would come in contact with "exposed" seleniferous materials.

Their concern is shared by Wyoming mining and regulatory personnel. However, the challenge has been to quantitatively assess selenium in the mining environment. Compounding the mining/selenium issue has been the national interest generated when selenium was found in the Kesterson Wildlife Refuge of California and more regionally in the Kendrick Irrigation Project of Wyoming (See et al., 1992).

Selenium in the mining environment was not of primary concern to the Wyoming coal industry until November 1984, when the Wyoming Department of Environmental Quality (WDEQ), revised the definition of overburden suitable for placement locations (Guideline No. 1 "Topsoil and Overburden" 1984). With respect to selenium, suitability limits were reduced from 2.0 ppm to a "marginal" suitability level of 0.1 ppm extractable selenium.

The mining industry was forced to seriously consider the effects of this revision on mining because significant amounts of overburden exceed the revised criteria of 0.1 ppm extractable selenium. This overburden criteria necessitated special handling procedures. Some of the other issues and concerns that have surfaced and apply to the mining environments include:

1. The Kesterson and Kendrick Irrigation Projects, both typically used as examples of environments in which selenium has had deleterious effects on wildlife, are no-outlet irrigation projects. Neither are mining-related, and neither address hydrologic environments similar to those found in mining environments such as the Powder River Basin. Correlating Kesterson, Kendrick, and surface coal mining in the Powder River Basin thus becomes difficult.

2. Selenium extraction and analytical techniques are still undergoing development and change. The inability to duplicate and repeat analytical results between, and even within, laboratories points to the need for standard operating procedures.

3. The 1984 suitability limit of 0.1 ppm extractable selenium was based, in part, on greenhouse experiments that focused on the development of multiple element extractants - not the correlation between selenium levels in soil and the uptake of selenium by plants as this study has been used (Soltanpour and Workman, 1980).

4. Limited baseline information is available on pre-mining levels of selenium in vegetation, soil, or waters of the Powder River Basin in Wyoming.

5. Limited information is available on the uptake of selenium by vegetation species being used in reclamation in the Powder River Basin.

Due in part to the concerns noted above, and the substantial costs associated with special handling large quantities of overburden, the Wyoming Mining Association and the WDEQ decided to jointly address the selenium issue. In December 1990, a joint project was proposed and three subcommittees were formed to address selenium in the mining environment. Those three subcommittees have focused on regulatory affairs, hydrology, and the combined issues of soil, vegetation, overburden, and wildlife. Each subcommittee is composed of members from the coal industry, the WDEQ, and the University of Wyoming or comparable research-oriented organizations.

Two objectives of the committees are to establish current and applicable selenium sampling and analytical procedures. Other key objectives are to identify:

- selenium levels in the pre- and postmining environments of the Powder River Basin;

- predictive relationships between selenium in the environment and target organisms;

- appropriate suitability levels for selenium in postmining backfill.

These objectives are being met by a multi-phase research project. This paper focuses on the accomplishments, to date, of the "Joint Subcommittee on Soil, Overburden, Vegetation, and Wildlife" (SVOW).

METHODOLOGY

The research was divided into three phases to assure proper identification of all variables and develop field and laboratory techniques for consistency and reliability. Many of the coal mining operations in the Powder River Basin are participating in this research. Phase I consisted of identifying vegetative selenium levels for both native and reclaimed lands. Phase II, which is in progress, will evaluate the correlation of plant selenium concentrations with selenium in overburden, soil, and backfill spoil material. Phase III will attempt to identify the effect of selenium on target organisms.

Phase I

The Phase I survey of vegetative selenium levels on premining and postmining lands has been completed. Sample sites were both randomly and selectively chosen. Random sampling was designed to describe the average or typical levels of selenium in plants in coal mine related disturbances of the Powder River Basin. Selective sampling focused on locations where selenium levels are likely to be high. Vegetation was selected for Phase I to provide a basis for more detailed study of variables that may contribute to selenium changes resulting from the mining process.

Native and Reclaimed Site Selection

All premine areas from which overburden will be removed (native sites), or areas that have been reclaimed (reclaimed sites), were identified and mapped for each mine. A 100 foot grid was overlaid on both native and reclaimed area maps. Each grid center was numbered. For native sites, one sample location was selected using a random numbers table for every five hundred acres of overburden removal. For reclaimed sites, one sample location was selected for each fifty acres of reclaimed land.

The sites were then located in the field. Standard vegetation field site selection techniques were used to randomly locate each site within the plot. Areas devoid of vegetation were re-located. Additional samples were collected from known seleniferous areas using existing overburden or plant data. Each sample location was permanently marked in the field, labelled, and photographed. Preselected characteristics of each site were documented on a standardized data sheet.

Sample Time

Vegetation samples were collected between bolting and flowering of western wheatgrass. This timing allowed consistency in the phenology of the vegetation sampled.

Sampling Procedure

One square meter plots were placed at the sample site locations. Vegetation cover, bare ground, litter and other cover characteristics of the site were estimated as outlined in

Guideline No. 2 (WDEQ-LQD, 1986). Life forms including warm season grasses, cool season grasses, shrubs, and forbs were sampled following cover estimation. Non-woody portions of the plants were collected. When all four life-forms were not present, the dominant individual species identified by cover, were sampled. Approximately, ten grams of plant material from each life-form was collected. Plants were immediately chilled in the field, frozen within eight hours, and transported to the lab within 60 hours of collection. Samples were kept frozen until analysis which occurred within two weeks of lab receipt.

Laboratory Preparation and Analytical Procedures

A modified perchloric acid/hydrofluoric acid/nitric acid method (Lim and Jackson, 1982) was used for plant digestion before analysis. Inductively Coupled Argon Plasma Atomic Emission Spectrometry (ICAP-AES) was used for selenium analysis on the digested samples.

Phase II

A Phase II pilot study was initiated in the fall of 1992. A single soil sample was collected from a selection of Phase I vegetation sites. These sites were selected to represent a range in plant selenium levels. The pilot study was initiated to help select sites to determine the predictive relationship between soil/spoil and vegetation selenium levels.

The pilot Phase II soil samples were taken in accordance with the Wyoming Standard Operating Procedures (SOP) for Selenium Sampling and Analysis of Overburden, Spoil, and Soil (1992). This SOP was developed by the SVOW subcommittee. Both AB-DTPA and Hot Water Soluble extractable selenium were determined in accordance with this SOP and reported for each sample. Extraction procedures were used to maintain continuity with the existing Powder Basin data set.

Rooting zone material was sampled for native areas from a composite of the overburden 24 to 36 inches below the surface. For reclaimed areas, the backfill was sampled from a composite of the zone immediately below the soil-spoil interface.

Samples from the Phase II pilot study will be used to further refine the selection of sites for the full scale Phase II study. Vegetation will be resampled together with the soil, overburden, and backfill. The sites selected for the full scale Phase II will be characterized in detail. Because of the complex nature of determining plant available selenium, several different soil extraction methods will be used to discover the method that best predicts selenium in plants. Other research being funded by the Wyoming Abandoned Mine Lands (AML) Division will be used to assist in the selection of the method most appropriate for soil analysis.

Phase III

A primary goal of Phase III research is to ascertain the effects of selenium levels in target organisms. The details on the methodologies to be used will depend on the outcome of the first two phases. The Wyoming AML Division has funded other research that will address the effect of selenium on animals. Results from that research will be used to refine the scope and better define the Phase III methodology.

RESULTS

Only preliminary selenium levels from Phase I of the research project described above are provided here. Phase I data is currently being evaluated by correlation, non-parametric and other advanced statistical methods. Results of these evaluations will be presented during the 1993 Billings Mined Land Reclamation Symposium.

Two hundred fifty-three samples were collected over the two-year sampling time frame. Of these, 116 were collected in 1991, and 137 were collected in 1992. One hundred forty-six of the samples were collected from native sites not yet disturbed by mining, and 107 samples were collected from reclaimed sites of various ages.

The primary objective of sampling was to estimate selenium levels in four growth-forms on native and reclaimed land: cool season grasses, warm season grasses, forbs, and shrubs. When one or more of the selected growth-forms were not present at a sample site, the most abundant species were sampled in place of the missing growth-form. In such cases, the most abundant species would have been sampled as part of the appropriate growth-form and also individually. Some information on selenium levels in individual species was thus obtained in conjunction with that collected for growth-forms.

In addition to sampling for selenium levels, vegetation cover values and values for a suite of environmental variables were estimated at each site. Environmental variables included percent cover of bare soil, date of backfill grading, date of topsoil replacement, date of permanent revegetation, depth of topsoil replacement, depth of the A+B horizons, slope position of the sample site, slope steepness of the sample site, orientation of the sample, signs of animals at the site, animal observations at the site, and the estimated average annual precipitation at the site. Interesting and valuable comparisons between native and reclaimed sites can be made using this information.

Not all environmental and vegetation cover information was collected at each site. In addition, not all sites reported selenium for all vegetation variables. Thus, zero and missing values resulted in different sample sizes for each variable. The size of each sample for each individual variable is presented in Table 1.

Table 1

Descriptive Statistics for Selected Environmental and Vegetation Variables.

	TOTAL VEGETATION COVER (%)	LITTER AND ROCK COVER (%)	BARE SOIL COVER (%)	TOTAL GROUND COVER (%)	COOL SEASON GRASS COVER (%)	WARM SEASON GRASS COVER (%)	SHRUB COVER (%)	FORB COVER (%)	DATE OF BACKFILL GRADING (year)	DATE OF TOPSOIL PLACEMENT (year)
COMBINED COUNT	232	232	218	234	216	93	93	153		
COMBINED MINIMUM	0.01	0.01	1	0.01	0.01	0.01	0.1	0.01		
COMBINED MAXIMUM	112	90	99	136	90	55	45	64		
COMBINED AVERAGE	35.3	40.8	29.3	79.4	17.7	7.8	9.9	8.2		
COMBINED STANDARD DEVIATION	18.1	21.1	23.5	26.4	12.2	9.6	10.3	11.9		
NATIVE COUNT	134	134	126	136	127	89	86	94		
NATIVE MINIMUM	6	1	2	7	1	0.01	0.1	0.01		
NATIVE MAXIMUM	96	80	95	136	89	55	45	40		
NATIVE AVERAGE	38.4	41.6	25.2	84.4	16.4	7.9	10.5	5.2		
NATIVE STANDARD DEVIATION	16.7	17.3	18.6	21.4	10.6	9.7	10.4	6.5		
RECLAIMED COUNT	98	98	92	136	89	3	6	59	91	98
RECLAIMED MINIMUM	0.01	0.01	1	0.01	0.01	2	1	0.01	1973	1975
RECLAIMED MAXIMUM	112	90	99	122	90	10	5	64	1992	1991
RECLAIMED AVERAGE	31.2	39.9	34.9	72.8	19.5	5.3	2.8	13.1	1985.2	1985.5
RECLAIMED STANDARD DEVIATION	19.2	25.5	28.2	30.8	14.0	4.2	1.7	16.3	4.3	3.7

Table 1 (Continued)

Descriptive Statistics for Selected Environmental and Vegetation Variables.

	DATE OF PERMANENT REVEGETATION (year)	DEPTH OF TOPSOIL REPLACEMENT (inches)	DEPTH OF THE A+B HORIZONS (inches)	SLOPE POSITION (degrees)	SLOPE STEEPNESS[1]	DIRECTIONAL ORIENTATION OF THE SITE (degrees)	ANIMAL SIGN	ANIMALS OBSERVED	PRECIPITATION (inches)	COOL SEASON GRASS Se (ppm)
COMBINED COUNT				252	253	231	220	227	248	205
COMBINED MINIMUM				1	1	0	0	0	1	0.01
COMBINED MAXIMUM				7	4	360	3	4	15	3.6
COMBINED AVERAGE				3.1	2.1	169.1	1.1	1.0	11.9	0.48
COMBINED STANDARD DEVIATION				1.6	0.94	103.5	0.94	1.0	1.9	0.53
NATIVE COUNT			135	146	146	132	126	125	141	125
NATIVE MINIMUM			0.5	1	1	0	0	0	5.63	0.01
NATIVE MAXIMUM			48	7	4	360	3	4	15	3.6
NATIVE AVERAGE			10.8	3.3	2.1	164.1	1.2	1.0	12.0	0.44
NATIVE STANDARD DEVIATION			8.3	1.5	0.93	102.4	0.88	1.1	2.1	0.52
RECLAIMED COUNT	100	96		106	107	99	94	102	107	80
RECLAIMED MINIMUM	1975	2.08		1	1	0	0	0	1	0.01
RECLAIMED MAXIMUM	1991	60		7	4	360	3	4	15	3.25
RECLAIMED AVERAGE	1985.7	20.9		2.9	2.0	175.7	1.1	0.77	11.9	0.55
RECLAIMED STANDARD DEVIATION	4.2	9.1		1.6	0.95	105.1	1.0	0.90	1.7	0.53

Table 1 (Continued)

Descriptive Statistics for Selected Environmental and Vegetation Variables.

	WARM SEASON GRASS Se (ppm)	FORB Se (ppm)	SHRUB Se (ppm)	CRESTED WHEAT-GRASS Se (ppm)	THICKSPIKE WHEAT-GRASS Se (ppm)	STREAMBANK WHEAT-GRASS Se (ppm)	WESTERN WHEAT-GRASS Se (ppm)	WHEATGRASS SPECIES Se (ppm)	SLENDER WHEAT-GRASS Se (ppm)	BIG SAGEBRUSH Se (ppm)
COMBINED COUNT	82	122	65	18	45	11	85	19	9	11
COMBINED MINIMUM	0.01	0.07	0.01	0.1	0.01	0.01	0.01	0.1	0.01	0.1
COMBINED MAXIMUM	46.5	120	12.3	90	2.5	0.7	2.4	0.95	1.85	0.7
COMBINED AVERAGE	0.96	2.9	0.73	5.4	0.60	0.32	0.57	0.31	0.45	0.34
COMBINED STANDARD DEVIATION	5.1	13.0	1.4	21.1	0.63	0.23	0.47	0.26	0.55	0.22
NATIVE COUNT	63	79	65	10	21	6	44	7	9	10
NATIVE MINIMUM	0.01	0.09	0.01	0.2	0.09	0.01	0.1	0.1	0.15	0.1
NATIVE MAXIMUM	2.75	15.3	3	1.95	2.1	0.5	2.4	0.3	0.6	0.7
NATIVE AVERAGE	0.39	1.3	0.54	0.81	0.64	0.22	0.60	0.17	0.34	0.35
NATIVE STANDARD DEVIATION	0.41	2.6	0.54	0.55	0.63	0.19	0.51	0.063	0.16	0.23
RECLAIMED COUNT	19	43	24	8	24	5	41	12	4	1
RECLAIMED MINIMUM	0.01	0.07	0.1	0.1	0.01	0.1	0.01	0.15	0.01	0.25
RECLAIMED MAXIMUM	46.5	120	12.3	90	2.5	0.7	1.8	0.95	1.85	0.25
RECLAIMED AVERAGE	2.9	5.8	1.3	11.5	0.56	0.45	0.53	0.40	0.59	0.25
RECLAIMED STANDARD DEVIATION	10.6	21.5	2.5	31.7	0.64	0.23	0.44	0.30	0.85	---

Table 1 (Continued)

Descriptive Statistics for Selected Environmental and Vegetation Variables.

	ASTRAGALUS BISULCATUS Se (ppm)	BLUE GRAMA Se (ppm)	SMOOTH BROME Se (ppm)	JAPANESE BROME Se (ppm)	CHEATGRASS Se (ppm)	THREAD-LEAF SEDGE Se (ppm)	PRAIRIE SANDREED Se (ppm)	JUNE-GRASS Se (ppm)	ALFALFA Se (ppm)	RUSSIAN THISTLE Se (ppm)
COMBINED COUNT	4		6	4	13	8		16	8	
COMBINED MINIMUM	47		0.11	0.2	0.09	0.01		0.01	0.25	
COMBINED MAXIMUM	575		1.7	1.6	3.3	0.25		1.6	2.4	
COMBINED AVERAGE	310.7		0.55	0.78	0.89	0.14		0.30	0.75	
COMBINED STANDARD DEVIATION	288.3		0.60	0.70	1.0	0.089		0.22	0.69	
NATIVE COUNT	2	5	4	2	2	3	7	10	3	
NATIVE MINIMUM	47	0.15	0.01	0.2	0.2	0.09	0.09	0.1	0.4	
NATIVE MAXIMUM	575	0.4	1.7	0.2	0.4	0.25	0.75	0.9	0.55	
NATIVE AVERAGE	311	0.29	0.69	0.2	0.3	0.15	0.26	0.34	0.45	
NATIVE STANDARD DEVIATION	373.4	0.11	0.72	---	0.14	0.089	0.23	0.24	0.086	
RECLAIMED COUNT	2		8	2	11	5		6	5	7
RECLAIMED MINIMUM	76		0.22	1.15	0.09	0.01		0.01	0.25	0.5
RECLAIMED MAXIMUM	545		0.3	1.6	3.3	0.25		0.9	2.4	13.2
RECLAIMED AVERAGE	310.5		0.26	1.6	1.0	0.13		0.23	0.92	4.1
RECLAIMED STANDARD DEVIATION	331.6		0.056	0.31	1.1	0.087		0.18	0.85	4.6

Table 1 (Continued)

Descriptive Statistics for Selected Environmental and Vegetation Variables.

	NEEDLE-AND-THREAD Se (ppm)	**GREEN NEEDLE-GRASS Se (ppm)**	**DANDELION Se (ppm)**
COMBINED COUNT	25	27	4
COMBINED MINIMUM	0.07	0.09	0.1
COMBINED MAXIMUM	1.25	1.95	4.6
COMBINED AVERAGE	0.38	0.53	1.4
COMBINED STANDARD DEVIATION	0.32	0.50	2.2
NATIVE COUNT	15	14	1
NATIVE MINIMUM	0.09	0.1	0.1
NATIVE MAXIMUM	1	1.95	0.1
NATIVE AVERAGE	0.34	0.64	0.1
NATIVE STANDARD DEVIATION	0.27	0.59	---
RECLAIMED COUNT	10	13	3
RECLAIMED MINIMUM	0.07	0.09	0.28
RECLAIMED MAXIMUM	1.25	1.35	4.6
RECLAIMED AVERAGE	0.43	0.42	1.8
RECLAIMED STANDARD DEVIATION	0.40	0.35	2.4

[1] Slope Steepness: 1=flat, 2=gentle, 3=moderate, 4=steep

Frequency Analysis

Cover and Environmental Variables

Frequency analysis revealed reasonably normal distributions for most sample variables. After eliminating zero values, total cover of vegetation, and total cover of litter and rock combined appeared to be the most normally distributed of the variables. The distribution of cool season grass cover was bell-shaped, with most of the values falling between 5 and 30 percent cover. Warm season grass cover peaked between 1 and 10 percent, as did the cover of shrubs and forbs.

While cool season grass cover was greater than zero at all but two of the 218 sites for which cool season grass cover information was recorded, there was no cover of warm season grasses in 82 of the 175 sites for which that information was collected. Shrubs were found at 90 of the 183 sites for which shrub cover was recorded.

Frequency analysis showed continuous backfill grading, topsoil replacement, and permanent revegetation activities on reclaimed lands from 1973 onward, although more samples were collected from the 1986 through 1988 period than any other time. This reflects the relative youth of many of the mines participating in the sampling program. While topsoil replacement depths ranged from zero (at pre-SMCRA sites) to 48 inches, the great majority of reclaimed samples had replacement depths of 24 inches. In contrast, the majority of soil depths on native sites were between 6 and 12 inches. This soil depth may be related to the topographic location of samples collected.

Samples were taken most commonly on the backslopes of hills, followed by summit, footslope, shoulder, and toeslope locations. Far fewer samples were taken in drainages or playas. Most samples were taken on flat or shallow-sloping sites. Approximately one-quarter were taken on moderate slopes, and less than ten percent were taken on steep slopes. Site orientation was fairly evenly distributed throughout the cardinal directions, although there was positive bias towards east-facing slopes.

There was no sign of animals at approximately 30 percent of the sites; signs of animals were abundant at only about 9 percent of the sites. Animals themselves were observed at over half the sites, although not in abundance.

Finally, most of the sites reported average annual precipitation between 8 and 18 inches, with most sample sites reporting precipitation around 12 inches. Just over twelve percent of the sites reported precipitation equal to, or slightly greater than, eighteen inches.

Selenium Variables

In general, selenium levels for the vegetation growth-forms and species were much less normally distributed than were the environmental and vegetation cover variables. For the commonly encountered cool season perennial grasses, there was a noticeably bimodal distribution, with a peak around 0.2 ppm selenium, and a peak around 1.0 ppm.

Similarly, warm season grasses showed a peak in their frequency distribution around 0.2 ppm and again around 1.0 ppm. Forb selenium levels had slight bimodal distribution. The most frequent values occurred for forbs around 1-2 ppm. Shrub selenium levels were bimodal, with peaks at 0.2-0.3 and 1.0 ppm.

Thickspike wheatgrass (*Agropyron dasystachyum*) showed a normal frequency distribution, with a peak at approximately 1.0 ppm, while western wheatgrass (*Agropyron smithii*) was markedly bimodal, with a distribution similar to shrub selenium. Needle-and-thread grass (*Stipa comata*) showed a similar pattern. Most of the other individual species did not occur in a sufficient number of samples to draw conclusions about their frequency distributions.

Descriptive Statistics

Cover and Environmental Variables

Nineteen of the 23 environmental and cover variables, and 24 of the 63 selenium variables were selected for further evaluation. Table 1 provides descriptive statistics for each of these variables, stratified into reclaimed and native areas, as well as combined for the entire data set.

Total vegetation cover was approximately 7 percent higher on native than reclaimed ground, although both the extremes were encountered on reclaimed ground. The cover of litter and rock were equivalent on native and reclaimed lands. Reclaimed lands averaged approximately 10 percent more bare soil than did native lands.

The cover of cool season grasses was slightly greater on reclaimed lands than native; the combined mean was approximately 18 percent. Warm season grasses showed only half the cover on reclaimed versus native sites. Three of the 93 sites reporting warm season grass cover were reclaimed sites. Shrub cover percentages on reclaimed and native sites were three and eleven percent, respectively. Three reclaimed sites had shrub cover. Forb cover on reclaimed ground was almost triple that on native, with one-third of the sites reporting forbs found on reclaimed lands.

Reclaimed sample sites tended to be located near the top of hills; native sites closer to the bottom. Few sites were located in either open or closed drainages. According to the information presented in Table 1, reclaimed sites are more level than native areas.

Animal sign in both areas was essentially the same, although more animals were observed on native ground than reclaimed.

Selenium Variables

Selenium levels in cool season grasses were uniformly low. Reclaimed values ranged from 0.01 to 3.25 ppm with an average ($\bar{x}$) of 0.53 ppm and a standard deviation (SD) of 0.52. Native values ranged from 0.01 to 3.6 ppm ($\bar{x}$ = 0.44 ppm; SD = 0.52).

Warm season grasses averaged 2.9 ppm on reclaimed sites (SD = 10.6). These values ranged from 0.01 to 46.5 ppm. Nineteen of the 82 sites where selenium was sampled in the warm season grass growth-form, were reclaimed sites. The native sites had values ranging from 0.01 to 2.75 ($\bar{x}$ = 0.39 ppm; SD = 0.41).

Forbs were similar to warm season grasses; selenium values were higher on reclaimed than native areas. Forb samples were taken more frequently from reclaimed areas than native. Reclaimed forb values ranged from 0.07 to 120 ppm with an average of 5.8 ppm (SD = 21.5). Native values ranged from 0.09 to 15.3 ppm. The average for these sites was 1.3 ppm (SD = 2.6). The level typically believed to be of dietary concern is 5.0 ppm and over.

Values from the four Astragalus bisulcatus plants sampled were one to three orders of magnitude higher than any other value. High selenium levels in this species is not uncommon. Reclaimed site values ranged from 76 to 545 ppm with an average of 310.5 ppm (SD = 331.6). Values from plants of native sites ranged from 47 to 575 ppm with an average of 311 ppm (SD = 373.4).

Average selenium levels in alfalfa (*Medicago sativa*) on reclaimed land ranged from 0.25 to 2.4 ppm ($\bar{x}$ = 0.92 ppm; SD = 0.85). Native values ranged from 0.4 to 0.55 ppm ($\bar{x}$ = 0.45 ppm, SD = 0.086). The average values were below the level believed to be of dietary concern.

Twenty-four of the 89 shrub samples taken were from reclaimed areas. Those 24 samples averaged higher selenium values than the native areas. The reclaimed areas ranged form 0.1 ppm to 12.3 ppm with an average of 1.3 ppm (SD = 2.5). The native areas ranged from 0.01 to 3.0 ppm. The average of these sites was 0.54 ppm (SD = 0.54).

Greater values were detected in the eight samples of crested wheatgrass (Agropyron cristaum) taken from the reclaimed areas than the ten samples taken form the native sites. The values on the reclaimed areas ranged from 0.1 to 90 ppm with the average value of 11.5 ppm (SD = 31.7). The native areas ranged from 0.2 to 1.95 ppm. The average value was 0.61 ppm (SD = 0.55).

Western wheatgrass values were lower on reclaimed areas than native. Reclaimed areas ranged from 0.01 to 1.8 ppm ($\bar{x}$ = 0.44 ppm; SD = 0.44). Native areas ranged from 0.1 to 2.4 ppm ($\bar{x}$ = 0.60 ppm; SD = 0.51). Thickspike wheatgrass showed a similar trend as shown in Table 1.

Needle-and-Thread grass, a common pioneer species, showed slightly higher selenium levels on reclaimed lands. Reclaimed areas ranged from 0.07 ppm to 1.25 ppm ($\bar{x}$ = 0.43 ppm; SD = 0.40. Native sites ranged from 0.099 to 1.0 ppm ($\bar{x}$ = 0.34 ppm, SD = 0.27). Note that the variability of the values for the reclaimed areas were twice that of the native sites.

Selenium values in green needle grass (*Stipa viridula*) was lower on reclaimed land than on native land. Reclaimed values ranged from 0.09 to 1.35 ppm ($\bar{x}$ = 0.42 ppm; SD = 0.35). The native values ranged form 0.1 to 1.95 ppm ($\bar{x}$ = 0.64 ppm; SD = 0.59).

Prairie junegrass (*Koelaria cristata)*, thread-leaf sedge (*Carex filifolia*), cheatgrass (*Bromus tectorum*) and japanese brome (*Bromus japonicus*) are the other species that were sampled in a few sites. The complete list of species sampled and their associated selenium values are shown in Table 1.

CONCLUSIONS

A state subcommittee comprised of personnel from the Wyoming Department of Environmental Quality, Wyoming Mining Association, and University of Wyoming have developed a three phase project. This research will attempt to address the issue of selenium in pre- and postmining environments. Phase I consisted of site selection and characterization, vegetative cover survey and sampling, selenium analysis, and data compilation and evaluation. Frequency analysis and descriptive statistics for both environmental and vegetative variables were determined from 253 sample sites.

Evaluation of selenium in vegetation sampled from native and reclaimed lands was the principal objective for Phase I. The four vegetation life-forms (cool season grasses, warm season grasses, forbs, and shrubs) sampled indicated reclaimed lands had higher average selenium levels than native sites.

Both warm and cool season grasses had average values well below the levels of dietary concern. Shrubs had few samples with values above 5.0 ppm on reclaimed sites. However, for both reclaimed and native sites the average value was below 2.0 ppm. Only the average value (5.8 ppm) for forbs sampled from reclaimed sites was greater than the 5.0 ppm selenium value considered to be of dietary concern; however, reclaimed site forb selenium levels ranged from 0.07 to 120 ppm.

Of the 20 vegetation species evaluated, only two, crested wheatgrass and Astragalus bisulcatus averaged greater than 5.0 ppm selenium. In addition to the results presented here, Phase I data is also being evaluated by correlation, nonparametric, and other advanced statistical methods. Results of these evaluations will be presented during the 1993 Billings Mined Land Reclamation Symposium. Additional information on vegetation selenium levels will be accumulated throughout Phase II.

Phase II is currently in progress and is expected to result in information that can be used to determine if selenium levels analyzed in overburden, soil, or backfill can be correlated to selenium concentrations in vegetation. Results of Phase II are expected to be statistically evaluated in the Fall 1993 and will be presented to the Wyoming Department of Environmental Quality and the Wyoming Mining Association.

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EMPIRICAL STUDIES OF DIVERSE MINE DRAINAGES IN COLORADO: IMPLICATIONS FOR THE PREDICTION OF MINE-DRAINAGE CHEMISTRY

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and
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ABSTRACT

Based on a study of mine waters draining diverse mineral deposit types in Colorado, we show that mine-drainage composition is a readily predictable function of ore deposit geology, climate, and mining methods used. The main factors controlling pH and dissolved metal concentrations in the waters studied include: (1) the acid-buffering capacity of ore deposit gangue minerals and host rocks; (2) the types and abundances of sulfides and other metal-bearing minerals in the ore deposits; (3) the availability of sulfides for weathering; and (4) the extent to which the waters maintain contact with the atmosphere during weathering, thereby controlling (a) the availability of dissolved oxygen and (b) the extent of evaporative concentration.

Standard static and kinetic laboratory tests for predicting mine drainage chemistry are hindered by difficulties in obtaining truly representative samples and by the inability to carry out the tests over time periods longer than several months to a year. Our interpretation of drainage chemistry data in a geologic context is enabling us to develop predictive models for drainage chemistry that are not compromised by non-representative sample size or time scale. These empirical models should therefore greatly enhance current laboratory methods for the prediction of mine-drainage composition.

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INTRODUCTION

Mine drainage waters can carry significant loads of heavy metals and other toxic elements, and thus can have severe adverse impact on surface- and ground-water quality. As a result there have been significant efforts over the years to predict the composition of mine drainage waters that would result from new mining projects. These efforts have largely focused on static and kinetic laboratory tests using relatively small samples of ore and waste material (Ferguson and Morin, 1991). Uncertainties in the results of these engineering tests can arise due to a number of factors (Ferguson and Morin, 1991), including whether: (1) the short time scales of laboratory-based studies can be extrapolated to make longer-term predictions; (2) the laboratory studies accurately reproduce geochemical conditions present in the field, and; (3) the small sample sizes considered in laboratory tests are truly representative of the larger-scale mineral deposit.

Another approach to predicting mine-drainage composition that has received much less attention over the years is one that interprets the composition of existing mine drainages in the context of various parameters such as ore deposit geology, climate, and mining method. Wildeman et al. (1974) showed that the composition of waters draining mines in various Colorado Front Range mining districts could be correlated with ore deposit mineralogy, and concluded that pyrite content was the most dominant factor controlling drainage composition. Wentz (1974) characterized the composition of different Colorado rivers affected by acid-mine drainage, and considered to a limited extent the influence of the geology and geochemistry of the mineral deposits.

In this paper we present results of an ongoing empirical study of mine drainages in diverse ore deposit types in Colorado (Ficklin et al., 1992; Plumlee et al., 1992; Smith et al., 1992; Smith et al., this volume). This study extends the results of those carried out by Wildeman et al. (1974) and Wentz (1974), by evaluating a greater diversity of mineral deposit types and examining in greater detail important geologic and geochemical controls on drainage composition. The results provide new insights into the dominant processes that control mine-drainage composition, and show that drainage composition varies as a function of ore deposit geology and the mining method used (underground vs. open-pit, etc.). Our interpretation of drainage composition data in a geologic context is enabling us to develop improved predictive models for drainage composition that are not compromised by non-representative sample size or time scale. These empirical models should therefore greatly enhance current laboratory methods for the prediction of drainage composition. We are currently compiling data on drainage chemistry for a variety of other mineral deposit types and climates not found within Colorado (to be presented in Plumlee et al., 1993), in order to make the predictive capabilities of this technique as broadly-applicable as possible.

ORE DEPOSIT GEOLOGY

We have evaluated mine and natural drainages from a spectrum of ore deposit types in Colorado containing a broad range of ore and gangue mineralogies, host rock lithologies, wallrock alteration, and trace element signatures (Fig. 1). Geologic characteristics of the deposit types sampled are presented in Table 1, and the drainages sampled are listed according to deposit type in Table 2. For more detailed information about the geology of these deposits, the reader is referred to Davis and Streufert (1990), and references contained therein.

SAMPLING AND ANALYTICAL METHODS

At each drainage site, water samples were collected at the adit or drainage source; where possible, the drainages were also sampled at progressive distances downstream. At each sample site, field measurements were made of pH, specific conductance, temperature,

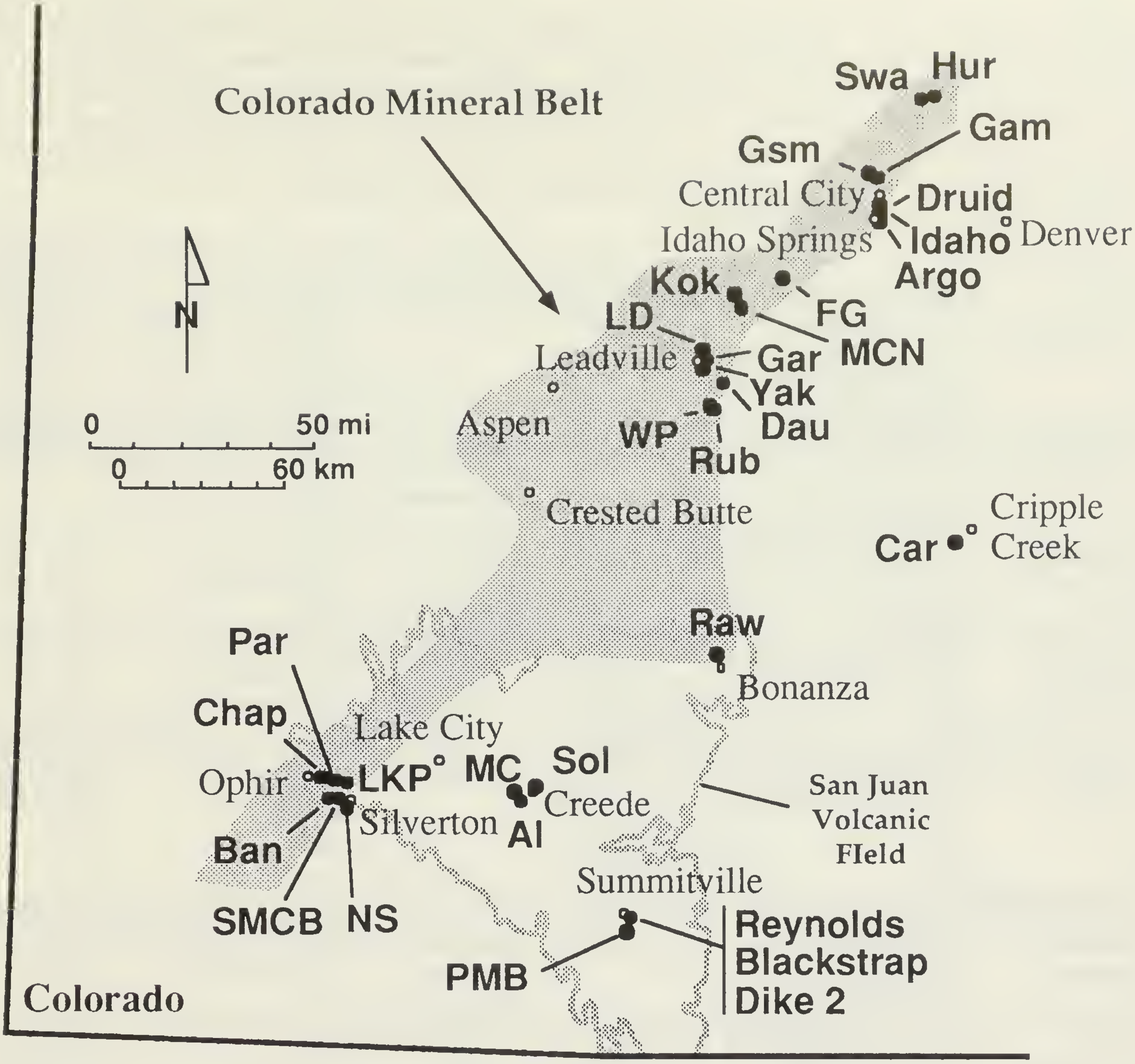

Figure 1. Map of the western part of Colorado, showing the location of the mine and natural drainages sampled relative to major towns, the Colorado Mineral Belt, and the San Juan Volcanic Field. Modified from Ficklin et al (1992) to incorporate new sites sampled.

alkalinity and/or acidity, and, where possible, dissolved oxygen content. Both unfiltered and filtered (0.1μm) water sample splits were collected at each sample site. Filtered and unfiltered splits were acidified with nitric acid for metal analysis. In addition, a filtered split was collected and acidified for analysis of dissolved iron species. An unacidified filtered split was collected for anion analysis. An unfiltered water sample was collected for hydrogen and oxygen isotopic analysis. Sulfate for sulfur and oxygen isotopic analysis was collected by acidification of a 0.1 μm-filtered water sample to less than pH 4.0, followed by addition of 1.0 M $BaCl_2$ solution to precipitate barite ($BaSO_4$); the precipitate was filtered later in the laboratory.

Metal concentrations were determined by atomic absorption spectrophotometry (Aruscavage and Crock, 1987), inductively coupled plasma-atomic emission spectroscopy (ICP-AES, Lichte and others, 1987), and inductively coupled plasma mass spectrometry (ICP-MS, using a technique under development at the U. S. Geological Survey, A. L. Meier, oral comm., 1992). Selected mine-drainage compositions determined in this study are listed in Table 3. For the purposes of this report, we consider only samples collected at the drainage source (such as an adit or spring), and samples that were filtered prior to analysis.

Table 1. Examples of of ore deposits in or near the Colorado Mineral Belt, and their geologic characteristics. Minerals listed in order of decreasing abundance. Data from references cited in text. Mineral abbreviations: py-pyrite; mc-marcasite; en-enargite; cov-covellite;cpy-chalcopyrite; qtz-quartz; S-native sulfur; td-tetrahedrite;bar-barite;sl-sphalerite;gn-galena; Ag-native silver; carb-misc. carbonates (including calcite, dolomite, or rhodochrosite); adul-adularia; tell-tellurides (including Au-tellurides); fluor-fluorite; W-tungsten minerals; moly-molybdenite.

Type	Description	Mineralogy	Host rock	Alteration	Elements
Acid-sulfate epithermal	Disseminated sulfides in intensely acid-altered volcanic centers	Py, mc, en, cov, cpy, qtz, S, td, bar	Volcanics	extensive alteration to silica, alunite, kaolinite, clays	Cu, Au, Ag, As, Zn, Pb
Porphyry Molybdenum	Disseminated, vein, and stockwork ores associated with igneous intrusions	Central moly, qtz, fluor. Distal py, sl, gn, carbs	Igneous intrusives & surrounding rocks	Silicification	Mo, lesser Cu & F
Igneous Polymetallic	Veins, disseminated ores in igneous host rocks	Py, sl, gn, qtz, carbs, ±W	Igneous intrusives; volcanics	Sericitization, silicification	Zn, Pb, Cu, Ag, Au
Adularia-sericite epithermal	Veins in volcanic host rocks	Sl, gn, py, cpy, nat. Ag, carbs, qtz, adul, bar	Ash-flow tuffs, other volcanic rocks	Silicification. Alteration to carbonates, clays	Zn, Pb, Cu, Ag, Au
Central City - type	Quartz-sulfide veins in metasediments	Central py, qtz. Increasing sl, gn, cpy, qtz, carbs peripherally	Metasediments	Sericitization, silicification	Zn, Pb, Cu, Ag, Au
High-sulfide carbonate-hosted	Sulfide-rich veins, replacement deposits in sedimentary rocks	Py, sl, cpy, gn, td, qtz, carb	Limestone, dolomite, sandstone, shale	Sulfide replacement of carbonates; silicification	Zn, Pb, Cu, Ag, Au
Gold-telluride	Gold-telluride veins associated with alkalic igneous activity	tell, bar, fluor, carbs, sulfates, minor py	Alkalic igneous rocks Metasediments	Silicification	Te, F, Au, carbonate, sulfate
Sherman-type carbonate-hosted	Sulfides replacing and filling open spaces in carbonate rocks; low pyrite	Low-mod. sulfide: bar, carb, sl, gn, py	Limestone, dolomite / silicification	Silicification	Zn, Pb, Ag

METAL-pH CLASSIFICATION SCHEME

The results of the study to date confirm that not all mine drainage is acidic and that mine-drainage waters need not be acidic to carry high concentrations of dissolved metals. Due to the broad range in pH (from less than 2 to near 8) and dissolved metal concentrations (6-7 orders of magnitude) measured, we have found it convenient to classify drainage compositions according to pH and the sum of dissolved base metals Zn, Cu, Cd, Pb, Co, and Ni (Figure 2 and Ficklin et al., 1992). These base metals are of significant concern environmentally, and are the dominant heavy metals present in nearly all drainages sampled. We have established nine different classes of metal-pH values that are based on general groupings of the data (Figure 2 and Ficklin et al., 1992, Plumlee et al., 1992). Boundaries between these classes have not been defined on a geochemically-rigorous basis. Concentrations of the base metals

Table 2. Drainage sites sampled in this study, grouped according to deposit type. Deposit types are listed in general decreasing order of acid-generating capacity. Locations are shown on Figure 1. Abbreviations in "Drainage type" column are as follows: N-natural; H-historic; M-modern; U-underground workings; C-collapsed tunnel; M-mine dumps; O-open-pit; R-under remediation.

	SAMPLE	Field ID	Mining District	Drainage type
Acid-sulfate Epithermal	Longfellow Tunnel	Long	Silverton	HU
	Kohler Tunnel	LKP	Silverton	HUD
	Dike 2	Dike 2	Summitville	MD
	Blackstrap	Blackstrap	Summitville	MO
	Reynolds Tunnel	Reynolds	Summitville	HMU
Porphyry Molybdenum	Climax Mine	MCN1, 2	Climax	MDR
Igneous Polymetallic	Pennsylvania Mine	Penn	Argentine	HUC
	Garibaldi Mine	Gar	Leadville	HUC
	Yak Tunnel	Yak	Leadville	HUR
	Chapman Gulch 2	Chap2	Ophir	N
	Chapman Gulch 3	Chap3	Ophir	HUC
	Paradise Portal	Par 1, Par up	Ophir	HUC
	Pass Me By	PMB	Summitville	HUC
	S. Mineral Creek	SMCB	Silverton	N
Adularia-sericite Epithermal	Rawley Tunnel	Raw	Bonanza	HUC
	Alpha Corsair Mine	Al	Creede	HU
	Miner's Creek	MC	Creede	HU
	Solomon Mine	Sol	Creede	HU
	American Tunnel	Am	Eureka	HMUR
Central City-type	Argo Tunnel	Argo	Central City	HU
	Druid Mine	Druid	Central City	HDR
	Tip-Top Mine	Gam-4	Central City	HU
	Gamble Gulch 6	Gam-6	Central City	N
	Idaho Mine	Idaho A, B	Central City	HUC
High-sulfide Carbonate-hosted	Wellington Mine	FG	Breckenridge	HUD
	Kokomo Mine	Kok	Kokomo	HUC
	Leadville Drain	LD	Leadville	HUR
	Bandora Mine	Ban	Silverton	HUC
Low-sulfide Carbonate-hosted	Dauntless Mine	Dau	Leadville	HU
	Ruby Mine	Rub	Leadville	HU
	Union Creek	WP	Leadville	N
Gold-telluride	Carlton Tunnel	Car	Cripple Creek	HU
	Huron	Hur	Eldora	HU
	Swathmore	Swa	Eldora	HU

taken individually, as well as those of dissolved iron, aluminum, and sulfate show generally similar trends with increasing pH as that shown by the sum of base metals.

The chemistries of the mine drainages studied and their position in the metal-pH classification scheme depend strongly upon a number of factors, including (1) properties of specific ore deposits, such as mineralogy, alteration, host rocks, structure, and trace element contents, (2) external parameters (such as the availability of atmospheric oxygen and the extent of evaporation) that are controlled largely by the mining method used (underground versus open-pit) and the presence or absence of mine dumps, and (3) geochemical processes such as mineral precipitation and metal sorption.

Table 3. Analytical results for selected mine drainages in Colorado. Analytical techniques listed in text.

Sample	Cu ppb	Zn ppb	Cd ppb	Ni ppb	Co ppb	Pb ppb	pH	SO4 mg/L	Al mg/L	Fe mg/L	Other elements
LKP	54000	120000	550	140	190	150	2.6	1700	60	430	As - 7 ppm
Reynolds	120000	20000	200	800	700	320	2.9	1900	130	310	As - 0.4 ppm; U - 0.04 ppm
Blackstrap	460000	390000	3000	21000	16000	<200	1.8	130000	5400	28000	As - 15 ppm; U - 3 ppm; Th - 4 ppm; Ce - 6 ppm; Be - 0.8 ppm
MCN	16000	24000	380	600	720	<5	1.9	4300	950	95	F - 710 mg/L; U - 90 ppm
Yak	2400	69000	290	40	20	10	4.4	640	2.6	2.4	
Chap2	1	40	<1	10	5	<5	7.9	600	<0.1	0.01	
Raw	1200	33000	150	40	50	5	6.0	600	0.4	24	
Sol	40	26000	160	10	80	1100	4.5	310	1.1	0.4	U - 0.02 ppm
Am	90	12000	60	20	40	<5	6.6	1300	2.5	19	
Argo	4500	30000	130	120	100	40	2.9	2100	29	120	
FG	270	170000	120	190	120	150	6.2	1800	0.2	87	
Kok	40	20000	40	10	7	<5	6.8	380	<0.1	12	
Rub	<1	20	<1	<5	<5	<5	7.8	5	0.1	<0.01	
Carlton	1	110	1	20	5	<5	7.7	1200	<0.1	0.02	

High-acid, extreme-metal and acid, extreme-metal

The lowest pH values and highest metal contents we have measured to date occur in open-pit waters and waters draining mine dumps of the acid-sulfate epithermal deposits at Summitville (Fig. 1). These extreme pH and metal values result because the Summitville ores are pyrite-rich but have very little buffering capacity in their host rocks or associated minerals. Pyrite (FeS_2), enargite (Cu_3AsS_4), covellite (CuS), and native sulfur were deposited in zones along which the host wallrock had been intensely acid-leached by acid magmatic gases, leaving silica, alunite ($KAl_3[SO4]_2[OH]_6$), kaolinite, and clays. Due to the abundance of Cu- and As-rich sulfides, the Summitville waters are also the richest in Cu and As of all drainages measured to date, with Cu greater than or subequal to Zn (hundreds of ppm) and As as high as 25 ppm. In addition to the 1000+ ppm sum of base metals, these waters also contain ppm- to tens-of-ppm-levels of other metals such as rare earth elements (REE), U, Th, Cr, and V, which are indicative of extensive dissolution of both ore and wallrock minerals. Hydrogen isotope shifts to heavy values (from near -120 to -65 permil δD) and corresponding increases in aqueous chloride concentrations (from less than 1 mg/L to as high as 96 mg/L) in the most metalliferous of the Summitville waters (Dike 2, Blackstrap samples) indicate that extensive evaporation occurred and likely contributed to the extreme metal concentrations. The Longfellow and Kohler tunnels near Silverton also drain ore deposits rich in enargite with relatively little buffering capacity in their wallrocks, and so their waters are also quite acidic and metal-rich. The other waters occurring in this class are those that drain pyrite-rich mine dumps in other deposit types, such as mine dumps at the Druid Mine near Central City. The high permeabilities of the mine dumps enhance evaporation, permit easy influx of atmospheric oxygen, and provide the waters with access to large amounts of sulfides for weathering.

Even more extreme metal contents (Zn and Cu concentrations in the g/L range) and acidities (pH values as low as -3) have been documented by Alpers and Nordstrom (1991) in waters draining underground workings of the Iron Mountain massive sulfide deposit in California; however, the same types of geologic controls on drainage composition are present as those we document in Colorado ore deposits with high-acid, extreme-metal drainages. At

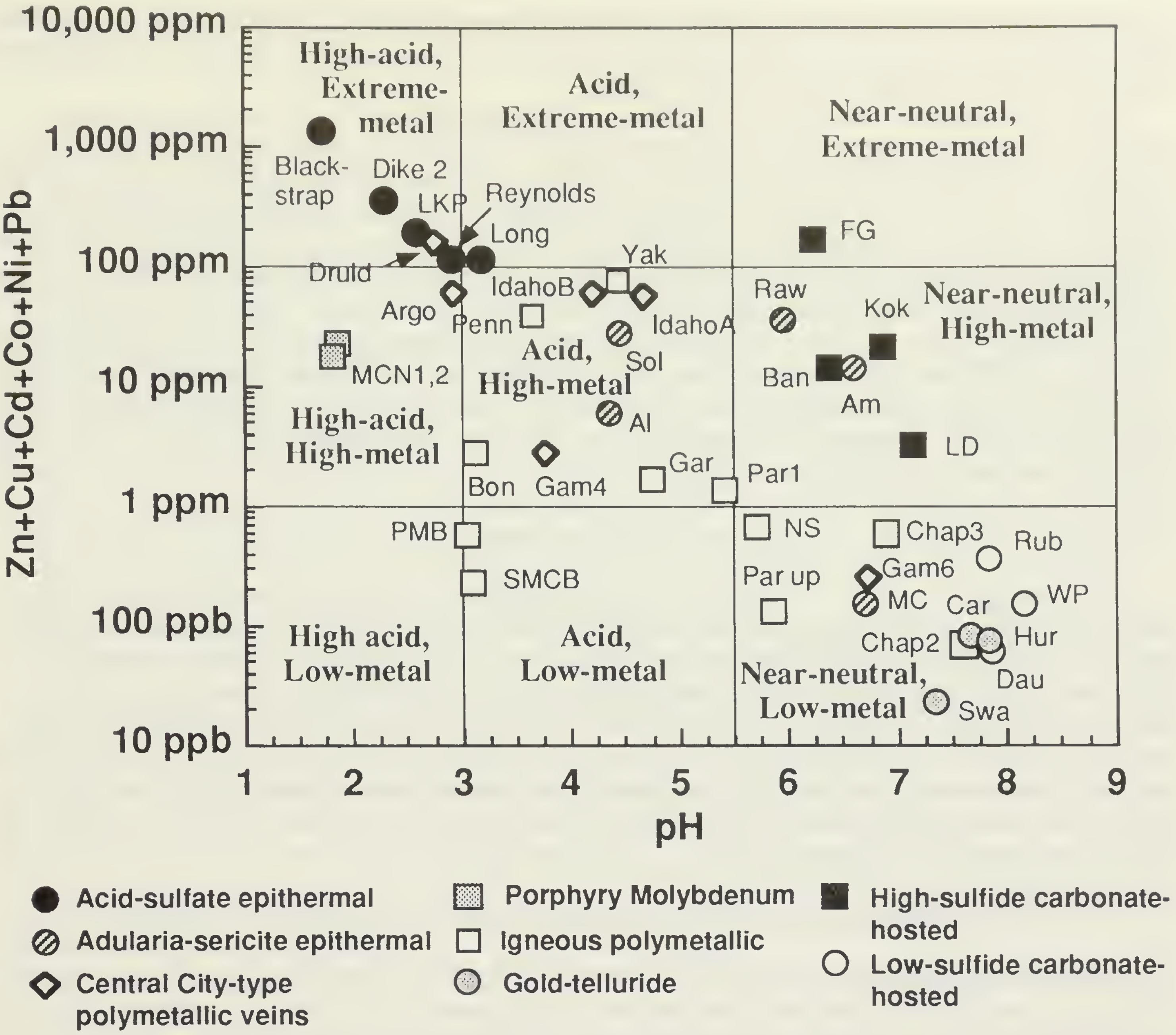

Figure 2. Variations in aqueous base metal concentrations (given as the sum of base metals Zn, Cu, Cd, Pb, Co, and Ni) as a function of pH for waters draining diverse ore deposit types in Colorado. A classification scheme based on pH and sum of base metals was proposed by Ficklin et al. (1992) based on the first year's sampling carried out in this study. The classes are labeled by bold text and are bounded by heavy lines. Sample locations and deposit types are given in Figure 1 and Table 2.

Iron Mountain, the ore is composed of lenses of massive pyrite with other base metal sulfides. The extreme acidities result from the oxidation of sulfides in these lenses and the lack of contact of the waters with surrounding metavolcanic host rocks, which are themselves relatively low in acid-buffering capacity (Alpers and Nordstrom, 1991). Although the waters drain underground workings, heat given off during sulfide oxidation leads to high ambient temperatures and extensive evaporation of the waters (Alpers and Nordstrom, 1991).

High acid-high metal, and acid-high metal

Waters in these two classes are of two main types. The first type, typified by the Argo, Yak, and Solomon mines, drain a variety of sulfide-rich deposit types that have low to moderate acid-buffering capabilities in their ore or wallrocks. These waters carry high concentrations of base metals (predominantly Zn), but generally do not carry significant concentrations of exotic metals such as REE. Most of these waters have high dissolved oxygen (DO) indicative of continued atmospheric contact. However, the waters do not have extreme metal concentrations because they drain mine workings (not mine dumps) in deposits where sulfides are contained in discrete veins, and thus have access to only limited volumes of sulfides and rock materials during weathering.

The second type of waters are those which drain molybdenite- and fluorite-rich waste dumps of the Climax porphyry molybdenum deposit (McNulty Gulch sample, Table 3); these waters fall in the high-acid, high-metal class (Figure 2). Low pH values (near 1.9) presumably result from the oxidation of pyrite present in the waste dumps and the lack of buffering reactions with the silicate-rich dump material. However, non-extreme Zn and Cu concentrations (20-40 ppm each) probably reflect the relatively low amounts of sphalerite and chalcopyrite in the Climax ores. Due to the large amounts of fluorite in the waste dump material and their low pH, the Climax dump waters have extreme fluorine concentrations near 900 mg/L. Interestingly, uranium is the dominant metal in the Climax waters other than iron and aluminum; the extreme U concentrations near 90 ppm most likely result from the low pH of the waters, the U-enriched granitic intrusive host rocks, and the high availability of F in the waters to complex the uranium.

Acid-low metal

Two drainages sampled to date have acid pH values but carry low dissolved base metals (less than 1 ppm sum of metals); these include the Pass-Me-By mine near Summitville and the natural acid drainage along South Mineral Creek near Silverton (Fig. 1). Both these waters drain pyrite-rich disseminated sulfide mineralization in rocks with moderate to low acid buffering capacity. Both have low dissolved oxygen (< 5 ppm) but high sulfate (500-660 ppm) and dissolved Fe (50-140 ppm). The lack of base metal transport by these waters may be due to (1) low amounts of base metal sulfides in the ore deposits, and/or (2) the need for ground waters to have dissolved oxygen during weathering to stimulate microbial catalysis of sulfide oxidation (Nordstrom, 1982).

Near-neutral waters with extreme, high, and low metal contents

Drainages with the highest pH values occur in deposits with high acid buffering capacities, including those with (1) carbonate host rocks or abundant carbonate gangue minerals (Leadville Drain, Bandora, French Gulch, Kokomo mines), (2) host rocks altered to calcite-rich propylitic mineral assemblages (volcanic-hosted epithermal deposits drained by the Rawley Tunnel [Bonanza district] and American Tunnel [Eureka district]), or (3) host rocks containing abundant reactive aluminosilicate glasses (some volcanic-hosted epithermal deposits [Miner's Creek at Creede], and Au-Te deposits at Cripple Creek [Carlton Tunnel]). Host-rock composition can significantly affect water concentrations of some dissolved species. For example, waters which have interacted extensively with felsic volcanic rocks generally contain elevated Na (10-80 ppm), K (1-10 ppm) and Li (10-30 ppm).

Near-neutral waters with high to extreme dissolved base metal contents (as high as 270 ppm SM) drain mines in pyrite- and sulfide-rich deposits (Bandora, Rawley, Leadville Drain, French Gulch, Kokomo). These include waters with low DO (< 0.1 ppm) that carry no hydrous Fe-oxide (HFO) particulates in suspension, and waters with high DO (up to 8 ppm) that carry some HFO particulates. Zinc is generally the predominant heavy metal in these waters. The abundance of Zn reflects the lack of sorption by particulate HFO (Smith et al., this volume; Smith et al., 1992)

Near-neutral waters with low base metal concentrations form in deposits with low pyrite contents (Carlton, Swathmore, Huron, Miner's Creek, Dauntless). DO concentrations in these waters also vary widely.

SUMMARY OF CONTROLS ON DRAINAGE COMPOSITION

The dominant controls on drainage composition in diverse ore deposit types include geologic controls (such as mineralogy, host rock alteration, etc.), external controls (such as climate and mining method), and geochemical controls (such as mineral precipitation and sorption).

Geologic controls

Ore deposit geology is predominant in controlling the composition of most mine drainages. Listed in general order of decreasing importance, the significant geologic controls are:
1) Pyrite content. In general, the higher the pyrite content of the ores, the lower the pH and the greater the dissolved heavy-metal concentrations. The importance of pyrite content has been well-documented by previous researchers (i.e., Wildeman et al., 1974), and serves as the foundation for acid-base accounting predictive schemes.
2) Acid-buffering capacity of the ore deposit gangue minerals, host rocks, or host rock alteration assemblages. The greater the buffering capacity, the higher the pH. Again, carbonate mineral content has long been known to influence drainage pH. However, this study demonstrates that the buffering capacity can come from minerals other than carbonates, and that carbonate-bearing wallrock alteration assemblages can react with the drainage waters, thereby consuming hydrogen ions and significantly increasing drainage pH. Furthermore, this study shows that high acid-buffering capacity alone does not guarantee that drainage waters will contain low concentrations of dissolved heavy metals.
3) Accessibility of sulfides to weathering, and sulfide grain size. Sulfides occurring in large masses or disseminated throughout large bodies of rock will be more readily accessible to oxidation and weathering than sulfides that occur in low to moderate amounts along discrete fractures. Furthermore, fine-grained sulfides have a much greater proportion of surface area available for weathering than do coarse-grained sulfides.
4) Structural characteristics. These affect the accessibility of sulfides, acid-buffering minerals, and atmospheric oxygen during weathering. Large, throughgoing fractures (such as those found in epithermal vein deposits) tend to focus fluid flow and thus limit exposure to material only contained within the fracture. In contrast, highly fractured ore deposits provide significant opportunities for ground waters to interact with large volumes of sulfide-bearing (or acid-buffering) rock material.
5) Content of sulfides and metal-bearing minerals other than pyrite. This affects primarily the amounts and proportions of heavy metals and other toxic elements in drainage waters. For example, ores with dominant Cu-sulfides have drainage waters with Cu>Zn. Ores with As-bearing minerals such as enargite generally have very high As concentrations. Ores without significant base metal sulfides other than pyrite can have drainage waters with relatively low heavy-metal contents (i.e. Climax).
6) Trace element enrichments of ores and host rocks. This strongly affects the amounts and proportions of less common elements such as REE, As, U, F, etc. in the drainage waters. A prime example is the "symbiotic" relation between the high-F ores and the high-U host rocks at Climax, which results in extreme F and U concentrations in drainage waters. Such prediction of less common elements in mine-drainage waters is not readily achieved with standard laboratory predictive tests.

External Controls

Predominant external controls on drainage composition include:
1) Climate. Although we have studied drainages to date that fall primarily within one climate regime, climate clearly plays an important role in drainage composition. Major effects include the amounts of water available for ore body weathering, the extent of evaporation, changes in reaction rates under different temperature regimes, and others. We are currently expanding this study to ore deposits in other climate regimes in order to better characterize these effects.
2) Mining method used. This can ultimately control the accessibility of atmospheric oxygen, evaporation, and sulfides during weathering. In general, mine dumps and open-pit mining appear to promote the lowest pH values and greatest metal concentrations, due to the high availability of oxygen and the great opportunities for water-rock interaction and evaporation. Underground mining generally provides access for atmospheric oxygen (unless

the mine openings are collapsed or blocked), but limits opportunities for extensive water-rock reactions unless the ore deposit is highly fractured.

Geochemical controls

1) Evaporation. Data collected in this study on chloride concentrations and hydrogen isotopic compositions show that evaporation may be an essential process in the generation of mine drainages having the most extreme dissolved metal concentrations. The data show that evaporation is active even in relatively cool climates (for example the alpine environment at Summitville).

2) Accessibility of atmospheric oxygen. Oxygen is the dominant driving force for sulfide oxidation, both as the initiator of the oxidation process and as the energy source required by bacteria that catalyze pyrite oxidation at low pH values (Nordstrom, 1982). Based upon our data, high dissolved oxygen appears to be required to generate the high metal contents in acid mine drainages. High initial dissolved oxygen may also be requisite in the generation of the metal-rich, near-neutral-pH waters, but subsequent oxygen depletion prior to outflow may be requisite in order to avoid precipitation of HFO and sorption of heavy metals.

3) Mineral precipitation. Mineral precipitation likely controls the concentrations of some major and trace species in the drainage waters. Many of the drainages sampled are actively forming iron- and/or aluminum-bearing particulates; we are currently examining the mineralogy and composition of these particulates. Much more extensive mineralogical work on the drainage particulates is needed before the controls of mineral precipitation on drainage composition are clearly understood.

4) Sorption by particulate Fe- and Al-oxides. As shown by Smith et al. (this volume) and Smith et al. (1992), sorption by particulate Fe or Al oxides can be important for some metals and As, especially at pH values between 5 and 7. The amount of sorption depends upon the amounts of these solids present suspended in the drainage stream, the amounts of dissolved metals present in the waters, and the pH. Sorption most likely controls concentrations of Pb, and As in most drainages; Cu and to a lesser extent Zn, are less-readily sorbed, and Cd and Ni are generally not sorbed. Speciation calculations indicate that a number of the waters studied are undersaturated with respect to anglesite [$PbSO_4$]; Pb concentrations in these waters are most likely controlled instead by sorption of Pb onto particulates.

CONCLUSIONS

Our results provide new insights into the dominant processes that control mine-drainage composition, and show that drainage chemistry varies as a function of ore deposit geology and the mining method used (underground vs. open-pit, etc.). By interpreting data collected from diverse mine drainages in a geologic context, it is thus possible to develop empirical predictive models for drainage composition that are not compromised by non-representative sample size or time scale. These empirical models should greatly enhance current laboratory methods for drainage-composition prediction.

For example, it is clear that acid-sulfate epithermal deposits are likely to generate highly acidic waters capable of carrying extreme concentrations of heavy metals such Cu, Zn, Cd, Co, Ni, REE, Cr, U, Th, etc. Extreme care should therefore be taken in the development of such deposits, in order to minimize (1) contact of mine wastes with atmospheric oxygen, (2) evaporation in mine waste piles, and (3) interactions of water with mine wastes and open-pit rocks.

We are currently using the results of this study to develop a more quantitative, geologically-based model for mine-drainage prediction.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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ALUMINUM AND IRON SOLUBILITIES AS EFFECTED BY THE OXIDATION OF PYRITE IN COAL OVERBURDEN ENVIRONMENTS

K.J. Reddy[1]

ABSTRACT

Usually, in natural waters gibbsite ($Al(OH)_3$) and amorphous iron ($Fe(OH)_3$) solubilities regulate aluminum (Al^{3+}) and iron (Fe^{3+}) concentrations, respectively. However, an increase in the concentration of sulfate (SO_4^{2-}), due to the oxidation of FeS_2, can alter these solubilities in coal overburden environments. Objective of this research was to examine the effects of pyrite oxidation on the solubilities of Al and Fe in coal overburden environments. Unweathered and weathered samples were collected and were subjected for solubility studies. Samples were reacted with distilled-deionized H_2O from 14 to 28 days and suspensions were filtered through 0.45 μ Millipore filter. Clear extracts were determined for pH, total concentration of Al^{3+}, Fe^{3+}, and SO_4^{2-} as well as the concentration of other cations and anions. Ion activity products (IAPs) were calculated from these concentrations and compared with solubility products (K_{sp}s) of different Al^{3+} and Fe^{3+} solid phases. The oxidation of FeS_2 decreased the pH and increased the activities of Al^{3+}, Fe^{3+}, and SO_4^{2-} in overburden extracts. For unweathered samples, the IAPs suggested near saturation with respect to gibbsite. For weathered samples, the IAPs were saturated with respect to jurbanite $Al(OH)(SO_4).5H_2O$. The IAPs suggested that $Fe(OH)_3$ in unweathered samples and melanite ($FeSO_4.7H_2O$) in weathered samples may regulate Fe^{3+} activity. However, considerable uncertainty prevails in the literature regarding the K_{sp}s of iron solid phases.

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INTRODUCTION

Acidification of coal overburden and acid mine drainage (AMD) are common problems in the Appalachian coal mining regions of the eastern United States. Increased coal mining during the last two decades and a better recognition of the problem have resulted in more frequent identification of acidic coal overburden problems in the western United States, an area once considered not to have this problem (Arora et al., 1980; Dollhopf, 1984).

Coal overburden may contain significant amounts of inorganic (e.g., FeS_2 and CuS) and organic sulfur compounds (Dollhopf and Russell, 1984). These compounds oxidize when exposed to the atmosphere resulting in production of acidity (Caruccio and Geidel, 1984). Acidic conditions limit revegetation of overburden by decreasing the availability of plant nutrients and by increasing the toxicity of elements that become more available at low pH (Arminger et al., 1976; Barnhisel, 1977; Tucker et al., 1987). Furthermore, increased solubilities of toxic elements (e.g., Cd, Cu, Pb, Ni, and Zn), due to low pH, may increase the potential for contamination (Martin, 1974; Nordstrom et al., 1977; Wahler, 1978; Griffin et al., 1980) of natural resources (e.g., lakes, surface water, and groundwater). To effectively manage coal overburden containing FeS_2, it is necessary to understand the solubility relationships of Al and Fe.

In acid environments, Al and Fe solubilities are still frequently assumed to be controlled by hydroxides (e.g., $Al(OH)_3$, $Fe(OH)_3$). The aqueous geochemistry of Al and Fe, however, is significantly modified due to the oxidation of FeS_2. Furthermore, very little information is known about potential solid phases that regulate solubilities of Al and Fe in coal overburden environments, particularly from western United States. Thus, the purpose of this paper was to show the effect of pyrite oxidation on the solubilities of Al and Fe in coal overburden environments.

MATERIALS & METHODS

Coal overburden samples (two unweathered samples (A and B), two less weathered samples (C and D), and one highly weathered sample(E) were collected from the Dave Johnston Coal Mine Company, which is at the southern edge of the Powder River Basin, Wyoming. The content of FeS_2 in unweathered samples ranged $\approx$ between 0.1 and 0.4% (personal communication from Chester L. Skilbred, Glenrock Coal Company, Glenrock, Wyoming). Samples were sieved through a two-mm screen and were used for subsequent experiments. Fifty grams of each sample, in triplicate, were suspended in 150 ml of distilled-deionized H_2O in 250 ml flasks for solubility measurements. Four drops of toluene were added to the each sample suspension and closed tightly with a rubber stopper to minimize the oxidation of FeS_2.

Sample suspensions were agitated on a rotary shaker at 200 rpm under laboratory conditions (i.e., temperature of $25 \pm 1^{\circ}C$). The pH of the sample suspensions was monitored before and after each reaction. After reacting for 14, 21 and 28 d the sample suspensions were centrifuged and filtered through 0.45 μm Millipore filter. Each extract was divided into two subsamples. One was acidified with HCl to pH between 4.5-5.0 and other one was left unacidified. Unacidified extracts were analyzed for pH, Eh, total carbonate species, sulfate, fluoride, and chloride. Acidified extracts were analyzed for various cations, anions, and dissolved organic carbon (DOC). The pH was measured with an Orion combination electrode. The Eh was measured with an Orion platinum (Pt) electrode with a $Ag/AgCl_2$ reference electrode. The Eh readings were taken over a period of 0.5 to two hr until the drift was less than three mV. Stable readings were always obtained within two hr. Stability of the readings was confirmed in selected extracts by monitoring the readings over a period of 24 hr. From Eh measurements pe (-log e^- activity) was calculated. Carbonate species were measured by titrating extracts with standardized HCl to pH 8.3 and 4.5 end points. Calcium, Mg, Si, Al, Fe, Mn, and B were measured by inductively coupled plasma optical emission spectrometry (ICP-OES). Potassium and Na were measured by atomic emission. Copper, Zn, Pb, and Mo were measured by atomic absorption (AA) using a graphite furnace technique. Ion chromatography was used to measure the concentration of sulfate, fluoride, and chloride. The DOC was analyzed by the coulometric technique.

The speciation model GEOCHEM (Sposito and Mattigod, 1980) was used to calculate ion activities. This model uses total elemental concentrations and pH of extracts to calculate ion activities. From ion activities, ion activity products (IAPs) were calculated and compared with solubility products (K_{sp}s) to evaluate potential solid phases controlling the concentration of Al and Fe in overburden extracts. We assumed that IAPs within ± 0.50 log units of K_{sp}s of solid phases represented near saturation with respect to that solid phase. The variation within that range is accounted for by the uncertainty of IAP estimations and K_{sp} measurements (Stumm and Morgan, 1981).

RESULTS & DISCUSSION

The pH measurements before and after solubility experiments suggested that FeS_2 did not oxidize during the reaction time (i.e., 14-28 days). Selected chemical data of overburden extracts are listed in Table 1. Table 2, lists day 28 data deviation from mean values. For most of the samples, day 28 data were within the range, suggesting near steady state conditions. Therefore, day 28 data was selected for discussion. Ion activities of Al^{3+}, Fe^{3+}, and SO_4^{2-} in overburden extracts are summarized in Table 3. Also, included in the Table are pH and pe+pH. The pH ranged from 6.60 to 2.30 and pe+pH varied from 12.84 to 8.99. These conditions represented neutral to acidic and moderately reduced to oxidizing environments. Comparison between the pH of unweathered and weathered samples suggests that, as FeS_2 oxidized the pH decreased from 6.60 to 2.30. Furthermore, as pH decreased activities of Al^{3+}, Fe^{3+}, and SO_4^{2-} increased in overburden extracts.

In natural environments where pH is near neutral, Al^{3+} activities are generally very low and are assumed to be controlled by $Al(OH)_3$ (gibbsite) (Hem, 1970). However, in acid sulfate waters and acid mine waters Al^{3+} activities are not controlled by gibbsite, and it has been sugested that the solid phase $Al(OH)(SO_4).5H_2O$ (jurbanite) may control Al^{3+} activities (Van Breeman, 1973; Nordstrom, 1982). Potential solid phases controlling Al^{3+} activities in overburden extracts are shown in Table 4. The K_{sp} value for gibbsite was taken from Lindsay (1979) and for jurbanite and alunite, K_{sp} values were taken from Nordstrom (1982). Overburden extracts, having a pH range between 6.60 and 5.13 suggested a near saturation with respect to gibbsite. However, at low pH of 2.30 (highly weathered) extracts were undersaturated with respect to this solid phase, and Al^{3+} activities were near saturation with respect to jurbanite. Same extracts also suggested either a high degree of oversaturation or undersaturation with respect to alunite.

Acid mine water resulting from the oxidation of FeS_2 may precipitate a number of secondary iron phases (Table 4), including $Fe(OH)_3$ (amorphous iron), $KFe_3(SO_4)_2(OH)_6$ (jarosite), $FeSO_4.7H_2O$ (melanite) (Nordstrom, 1982). The log K_{sp} value used for amorphous iron is 4.89. This value was taken from Ball et al. (1981). From pH 6.60 to 2.30, samples A and D suggested near saturation with respect to amorphous iron and other samples suggested undersaturation with respect to this solid phase. The log K_{sp} value of 4.89 for amorphous iron is uncertain. Chapman et al. (1983) used a value of 3.00 in their calculations. Use of their value suggested undersaturation with respect to amorphous iron for all samples.

The log K_{sp} value for melanite in terms of Fe^{3+} is -17.70. This value was calculated from the following reactions:

$$
\begin{array}{lrr}
FeSO_4.7H_2O \leftrightarrows Fe^{2+} + SO_4^{2-} + 7H_2O & -4.66 & (1) \\
Fe^{2+} \leftrightarrows Fe^{3+} + e^- & -13.04 & (2) \\
\hline
FeSO_4.7H_2O \leftrightarrows Fe^{3+} + e^- + SO_4^{2-} + 7H_2O & -17.70 & (3)
\end{array}
$$

The value for reaction 1 was taken from Ball et al. (1981) and value for reaction 2 was taken from Lindsay (1979). All extracts between pH of 6.60 and 5.13 suggested undersaturation with respect to melanite. However, at low pH of 2.30 extracts were near saturation with respect to melanite. Again, K_{sp} value for melanite is also questionable, because K_{sp} value reported by Ball et al. (1981) for this solid phase is less soluble than the recent value of -2.46, which makes all extracts in this study highly undersaturated with respect to melanite. Chapman et al. (1983) reported a K_{sp} value of -93.21 for potassium jarosite. Comparison of IAPs with this K_{sp} suggested that all extracts were undersaturated with respect to potassium jarosite.

Results in this study show that before oxidation of FeS_2, gibbsite will control the activity of Al^{3+}. However, as FeS_2 oxidation takes place the pH decreases and SO_4^{2-} activity increases. Under such conditions, jurbanite will control Al^{3+} activities in coal overburden extracts. Results obtained on iron solid phases are not convincing, but indicate that amorphous iron before oxidation of FeS_2 and melanite after oxidation of FeS_2 may have potential for controlling Fe^{3+} activities in coal overburden environments.

CONCLUSIONS

The oxidation of pyrite (FeS_2) is considered as the main source for acidity in coal overburden environments. The Al and Fe solubilities as effected by the oxidation of FeS_2 in coal overburden samples was examined in this study. Results suggested that oxidation of FeS_2 decreased the pH and increased the activities of Al^{3+}, Fe^{3+}, and SO_4^{2-}. The Al^{3+} activities in unweathered and less weathered samples (pH from 6.60 to 5.13) suggested near saturation with respect to gibbsite. In highly weathered samples (pH of 2.30), Al^{3+} activity appeared to be controlled by jurbanite. Saturation indices based on early estimation of solubility products reported in the literature suggest amorphous iron be near saturation for unweathered and less weathered samples. The Fe^{3+} activities for highly weathered samples suggested near saturation with respect to melanite. All samples suggested a high degree of undersaturation with respect to potassium jarosite. Nonetheless, considerable uncertainty prevails in the literature regarding the solubilities of amorphous iron, melanite, and potassium jarosite. Further research regarding the solubilities of these solid phases in acid mine waters is needed.

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Table 1. Selected chemical data of overburden water extracts, mean of triplicate analysis. UW = unweathered, LW = less weathered, and HW = highly weathered.

Reaction time (days)	pH	Eh (mV)	Al^{3+}	Fe^{3+}	SO_4^{2-}
			--------(-log mol L^{-})-----------		
Sample A (UW)					
14	6.59	280	4.30	5.16	2.60
21	6.51	330	5.60	5.20	2.57
28	6.60	321	6.10	5.15	2.57
Sample B (UW)					
14	5.48	259	5.82	5.48	2.04
21	5.67	234	5.73	4.25	2.06
28	5.61	220	5.80	4.16	2.07
Sample C (LW)					
14	5.60	235	5.31	5.10	2.36
21	5.47	200	5.32	5.10	2.37
28	5.43	211	5.35	5.12	2.38
Sample D (LW)					
14	5.37	394	6.43	3.87	2.39
21	5.17	412	5.50	3.83	2.38
28	5.13	410	5.47	3.84	2.41
Sample E (HW)					
14	2.23	629	2.13	2.19	1.28
21	2.40	625	2.15	2.24	1.31
28	2.30	624	2.14	2.24	1.30

Table 2. Day 28 data deviation from mean values for coal overburden water extracts.

Sample	pH	Eh (mV)	Al^{3+}	Fe^{3+}	SO_4^{2-}
			---------(-log mol L^{-})---------		
A (UW)	6.56	310	5.33	5.17	2.58
Deviation	±0.03	±10.6	±0.76	±0.02	±0.10
B (UW)	5.58	238	5.78	4.63	2.05
Deviation	±0.02	±18.0	±0.01	±0.47	±0.01
C (LW)	5.50	215	5.32	5.07	2.37
Deviation	±0.07	±4.3	±0.02	±0.04	±0.01
D (LW)	5.22	405	5.80	3.84	2.39
Deviation	±0.09	±4.6	±0.33	±0.006	±0.01
E (HW)	2.31	626	2.14	2.22	1.29
Deviation	±0.01	±2.0	±0.001	±0.001	±0.003

Table 3. Ion activities of Al^{3+}, Fe^{3+}, and SO_4^{2-} in overburden water extracts from 28 days reaction time, mean of triplicate analyses.

Sample	pH	pe+pH	Al^{3+}	Fe^{3+}	SO_4^{2-}
			-----------------(-log)---------		
A (UW)	6.60	12.02	11.22	14.59	2.76
B (UW)	5.61	9.32	8.18	14.37	2.41
C (LW)	5.43	8.99	7.29	15.83	2.62
D (LW)	5.13	12.04	7.07	10.73	2.68
E (HW)	2.30	12.84	3.48	5.07	1.89

Table 4. Potential solid phases controlling solubilities of Al and Fe in overburden water extracts from 28 days reaction time, mean of triplicate analyses. NS = near saturation, US = under saturation, and OS = over saturation.

Solid phase	log K_{sp}	A	B	C	D	E
$Al(OH)_3$ (gibbsite)	8.51	NS	NS	NS	NS	US
$Al(OH)(SO_4).5H_2O$ (jurbanite)	-17.80	US	US	US	US	NS
$KAl_3(SO_4)_2(OH)_6$ (alunite)	-85.40	US	OS	OS	OS	US
$Fe(OH)_3$ (amorphous iron)	4.89	NS	US	US	NS	US
$FeSO_4.7H_2O$ (melanite)	-17.70	US	US	US	US	NS
$KFe_3(SO_4)_2(OH)_6$ (jarosite)	-93.21	US	US	US	US	US

Planning, Rehabilitation and Treatment of Disturbed Lands
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CHARACTERIZATION OF SOILS, SPOILS, OR WASTES POTENTIALLY CONTAINING ACID FORMING MATERIALS

L.R. Hossner[1] and K.P. Raven[1]

ABSTRACT

The acid forming materials in mine tailings and spoils are primarily iron sulfides (FeS_2) that when exposed to oxidizing conditions generate sulfuric acid and eventually acid drainage. Acid forming materials can be characterized by determination of potential acidity or by weathering methods. Potential acidity has been assessed through total S, pyritic S or Fe, or directly using H_2O_2. If neutralization potential is evaluated then acid/base account, which is an index of the acid generating capacity of the sample, can be determined. Weathering methods include procedures such as the humidity cell and modified soxhlet techniques. Problems associated with the currently used methods are that the presence of siderite ($FeCO_3$) in the sample can unrealistically inflate the neutralization potential, calculations based on the general oxidation reaction of FeS_2 might lead to incorrect estimates since the stoichiometry seems to be more complex, and reaction rates are an important consideration in incubation or weathering studies. Thus, there is the need to better understand the stoichiometry and kinetics of the FeS_2 oxidation, with elucidation of reaction mechanisms. A combination of methods seems to be the best alternative to understand the acid generation capacity of a given sample.

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INTRODUCTION

Acid forming materials are defined as earthen materials that contain sulfide minerals or other materials which, if exposed to air, water, or weathering processes, form acids that may create acid drainage (Surface Mining Control and Reclamation Act, 1977). The iron sulfides (FeS_2), pyrite and marcasite, are generally believed to be the main cause of acidity and acid drainage from mine tailings and from coal and lignite mines. Sulfuric acid tends to be formed when FeS_2 is exposed to an oxidizing environment. Independently of the reaction path, chemical or biochemical, this process can be summarized by the following general equation (Temple and Koehler, 1954):

$$4\,FeS_2 + 15\,O_2 + 14\,H_2O = 4\,Fe(OH)_3 + 8\,H_2SO_4. \qquad [1]$$

The amount of acidity formed depends on the FeS_2 content of the material, its reactivity, and the activity of acidophilic Fe and S oxidizing bacteria. Mineralogy, crystallinity, trace element content, morphology, and particle size affect the reactivity of FeS_2. Surface area of FeS_2 seems to be the best indicator of reactivity (Pugh et al., 1984), although fine sulfide particles are sometimes coated with organic compounds (Finkelman, 1987). Marcasite is more reactive than pyrite at an equivalent surface area. The activity of acidophilic bacteria, such as *Thiobacillus ferrooxidans* and *Thiobacillus thiooxidans*, dramatically increases the rate of FeS_2 oxidation (Lorenz, 1962).

Since acid forming materials associated with coal and lignite mining can cause acid drainage and severely restrict revegetation of mine spoils, it is necessary to quantify the potential acidity in strata to be mined or for post mine evaluation. The first methods were indirect and based on the determination of FeS_2. Smittenberg et al. (1951) treated samples with a reductant composed of Sn and HCl and the released sulfide was measured by iodometric titration. Other methods using a similar extraction principle have been proposed (Murthy and Sharada, 1960; Aspiras et al., 1972; and Sorensen et al., 1979). Pons (1964) suggested a semi-quantitative microscopic method to estimate FeS_2 in soils. Pyrite in soils or mine spoils has also been estimated by total or pyritic S (Grube et al., 1971) or pyritic Fe (A.S.T.M., 1968). Caruccio (1975) proposed a method to estimate reactive FeS_2 through the combination of a microscopic technique and the FeS_2 content of the sample. Direct methods used to determine potential acidity of soil or mine spoils are based on tretament of samples with H_2O_2 (Yoneda, 1961; Grube et al, 1971; Sobek et al., 1978; and O'Shay et al., 1990) and on weathering studies (Caruccio, 1968; Sobek et al., 1982).

METHODS CURRENTLY USED TO CHARACTERIZE ACID FORMING MATERIALS

Potential Acidity

The potential acidity is the capacity of the soil or mine spoil to produce acidity over the long-term if conditions for this process are favorable. Potential acidity has been determined by several methods: total S concentration, FeS_2 content, and direct determination with H_2O_2. The FeS_2 content of a sample can be estimated from the total S or Fe concentrations of the sample after removal of other S or Fe forms, respectively. Calculation of the potential acidity from total pyritic S or Fe content data is based on the stoichiometry of the general FeS_2 oxidation reaction as given in equation 1.

The maximum potential acidity is determined from the total S concentration in the sample (Sobek et al., 1978). The furnace combustion method is a popular technique to assess the total S in a sample (LECO, 1975). The S in the sample is first combusted in the presence of O_2 at 1600°C in a furnace to yield SO_2. The SO_2 is then released in a titration vessel filled with a dilute HCl solution containing starch, KI, and traces of KIO_3. Iodine (I_2) is produced in the titration vessel through the reaction:

$$KIO_3 + 5\,KI + 6\,HCl = 6\,KCl + 3\,I_2 + 3\,H_2O \qquad [2]$$

and forms a blue complex with starch. When SO_2 comes into the titration vessel it reacts with I_2 through the reaction:

$$SO_2 + I_2 + 2\,H_2O = H_2SO_4 + 2\,HI \qquad [3]$$

and the blue color fades. A colorimetric detection device notices the color change in the titration vessel and a buret automatically releases KIO_3 into the titration vessel until the initial I_2 concentration and the initial solution color are regenerated. At the end of the determination the KIO_3 titrant consumption is read from the buret in terms of S content in the sample. New furnaces are equipped with an infra-red detector to assess SO_2 as a replacement for the automatic buret. The potential acidity is calculated considering that one mole of S generates two moles of H^+ (Equation 1). The maximum potential acidity is an adequate index of the potential acidity only when other S forms are present in insignificant amounts.

When sulfates and organic S are present in high amounts in the sample, total FeS_2-S is a much better measure of potential acidity than total S. Sobek et al. (1978) have described a procedure to determine different S forms in a sample. Three subsamples are used for this purpose. The first is used for total S determination (S_1). The second subsample is leached with ~ 5N HCl followed by leaching with water and the total S is determined in the residue (S_2). The leaching treatment is performed in order to remove sulfates. The third subsample is treated with ~ 2N HNO_3 overnight followed by leaching with water and the total S measured in the residue (S_3). This treatment removes sulfates and sulfides. The S forms in the samples are calculated as follows:

$$\text{Total S} = S_1 \qquad [4]$$

$$\text{Sulfate S} = S_1 - S_2 \qquad [5]$$

$$\text{Sulfide S} = S_2 - S_3 \qquad [6]$$

$$\text{Organic S} = S_3 \qquad [7]$$

The total FeS_2-Fe can be estimated by the procedure proposed by the American Society for Testing and Materials (A.S.T.M., 1968). The sample is initially leached with HCl to remove Fe oxides. The remaining sample is then treated with HNO_3 to dissolve FeS_2. The Fe concentration in the HNO_3 extract is then determined by atomic absorption spectrophotometry. It is assumed than the Fe in the extract is exclusively of FeS_2 origin. The potential acidity is calculated considering that four moles of H^+ will be generated for each mole of Fe present during FeS_2 oxidation (Equation 1). This method will overestimate the FeS_2 content of the sample, especially if a variety of Fe minerals are present (O'Shay et al., 1990).

The potential acidity can also be directly determined by treating the sample with H_2O_2 (Yoneda, 1961; Grube et al., 1971; Sobek et al., 1978; O'Shay et al., 1990). The principle is to oxidize FeS_2 according to the reaction:

$$2\,FeS_2 + 15\,H_2O_2 = 2\,Fe(OH)_3 + 2\,H_2SO_4 + 4\,H_2O. \qquad [8]$$

The sample is initially treated with HCl to destroy carbonates and washed with water to remove excess salt and acidity. The pretreated sample is then allowed to react with an excess of H_2O_2 on a hot plate. After completion of the reaction, the remaining H_2O_2 is decomposed and the acidity generated from oxidation of FeS_2 by H_2O_2 (Equation 8) is titrated with a NaOH solution. Although the procedure described by Sobek et al. (1978) was found unreliable (Sobek et al., 1987), a modified procedure (O'Shay et al., 1990) yielded accurate and reproducible results for Texas overburden samples.

Neutralization Potential

The neutralization potential of soils or mine spoils represents the inherent capacity they have to neutralize acidity. The sources of alkalinity include mainly carbonates and weatherable silicates. Carbonates act as natural soil buffers. The neutralization potential of a sample is determined by treating it with a known excess of HCl and once the reaction is completed the remaining acid is titrated with NaOH. There are two versions of this method: hot acid treatment (Sobek et al., 1978) and cold digestion (Caruccio and Caruccio, 1980). The hot digestion method determines a maximum neutralization potential (Banaszak, 1981), since it also neutralizes alkalinity released by dolomite and silicates, and generally yields reproducible results (Sobek et al., 1987).

Weathering Methods

The two most popular weathering methods are the humidity cell (Caruccio, 1968) and the modified soxhlet technique (Sobek et al., 1982).

The humidity cell technique consists of placing a sample into a humidified chamber and leaching it at regular intervals to remove the oxidation products. Leachates are then analyzed to evaluate the chemical processes that occur in the sample. Environmental factors affecting the weathering process can be easily controlled. The humidity cell has to be run for at least several weeks before consistent trends begin to appear.

The modified soxhlet technique consists of the continuous circulation of solvent, in this case H_2O, through an extraction chamber. Trends in acid production are obtained after a few days.

To obtain more rapid results, microbial weathering methods or bioassays may have to be considered. Duncan and Walden (1975) proposed a bioassay to determine potential acidity using slurries containing *Thiobacillus ferrooxidans.* Doolittle (1991) leached small overburden samples containing *Thiobacillus ferrooxidans* with water.

PROBLEMS WITH CURRENT METHODS

A source of acidity that is commonly not considered in pyritic systems is the exchange acidity. It consists of Al^{3+}, Fe^{3+}, and H^+ ions that are adsorbed onto negatively charged surfaces present in soils and sediments. Of these cations Al^{3+} is the most important under most soil conditions, however, under very acid conditons, Fe^{3+} is also important. Acidity is generated through hydrolysis reactions. This source of acidity has to be accounted for in acid systems with pH values lower than 5.6.

The presence of siderite ($FeCO_3$) in soil or sediment samples tends to inflate its neutralization potential and therefore lead to biased acid/base account values (Frisbee and Hossner, 1989; Doolittle et al., 1992). The neutralization potential determination will be affected due to the reaction of siderite with HCl:

$$FeCO_3 + 2\,HCl = FeCl_2 + H_2O + CO_2. \qquad [9]$$

In contrast, oxidized $FeCO_3$ sediments are reported to be acidic (Postma, 1983) and the oxidation rate of $FeCO_3$ is slow (Seguin, 1966). Since the rate of reaction of $FeCO_3$ with HCl is higher when heated, the acid digestion method of Sobek et al. (1978) seems to be particularly sensitive to this effect. $FeCO_3$, if it is present, will cause difficulty in evaluation of results regardless of the methodology chosen. Wiram (1992) proposed a modified procedure to determine the neutralization potential that uses H_2O_2 and takes into account the acidity generated by the oxidation of FeS_2 and of the Fe released by the $FeCO_3$. Nevertheless, more research is required in this area.

The general FeS_2 oxidation equation (Equation 1) is an oversimplification of reality, and its stoichiometry depends on environmental conditions (Sullivan and Essington, 1987). Depending on pH, redox potential, and leaching conditions processes that go along with the FeS_2 oxidation include release of Al^{3+} and other cations from aluminosilicates, hydrolysis of Fe^{2+}, Fe^{3+}, and Al^{3+} ions, and precipitation of Fe(II), Fe(III), and Al sulfates. All these processes definitely alter the oxidation pathway and stoichiometry and could explain the formation of solid phases not accounted for by the simple oxidation equation.

Chemical methods used for determining total FeS_2 composition only give gross amounts of potentially oxidizable FeS_2. FeS_2 morphology, surface area stoichiometry, and reaction rates are not known. Reaction kinetics have been described by several models (Vlek and Lindsay, 1978; Evangelou et al., 1983, 1985; Pugh et al., 1984; Brown and Jurinak, 1989 a, b). Doolittle (1991) demonstrated that at pH values greater than 4.0, reaction kinetics were zero order and the reaction rate was very slow. Nevertheless, when the pH dropped below 4.0, the reaccion followed first order kinetics. In calcareous systems, pH could be a very important consideration in evaluating reaction kinetics and rate.

Weathering methods can be used to determine reaction rates and kinetics but the stoichiometry is not known so in theory the process must be monitored for a considerable period of time in order to adequately describe the system. Disturbed samples of material are used and the reaction is measured under optimum conditions so the results do not mimic field conditions.

It appears that the current course of action available to one attempting to characterize acid forming materials is to evaluate the sample using a variety of methods. A determination of total FeS_2, the neutralization potential, and the presence of $FeCO_3$ are needed for each sample. In addition, valuable information can be gained from weathering studies, and an evaluation of kinetic data and the morphology of FeS_2 present.

NEEDS AND CONCLUSION

It is evident that current methodology is not completely satisfactory for evaluation of overburden materials and minesoils for acid forming materials. Rapid methods are still needed for the accurate and inexpensive determination of potential acidity and neutralization potential. An understanding of the extent and distribution of $FeCO_3$ in overburden strata is needed along with the ability to identify and evaluate it's influence on chemical methods. A better understanding of the stoichiometry and kinetics of FeS_2 oxidation would also lead to improved prediction of potential acid production.

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PYRITE OXIDATION AS INFLUENCED BY PARTICLE SIZE AND MORPHOLOGY

S.R. Jennings and D.J. Dollhopf

ABSTRACT

The generation of acid mine drainage as a consequence of sulfide mineral oxidation is a widespread source of resource degradation. The objective of this investigation was to evaluate the influence of sulfide mineral weatherability on acid generation processes. The influence of particle morphology, and not particle size, was found to exert the dominant control on rate of mineral weathering. Massive morphology particles generated acid at a significantly greater rate than euhedral morphology samples. Acid generation was a consequence of mineral dissolution which occurred nonuniformly across the surface of minerals during oxidation. Mineral surface weathering occurred at sites of excess energy including grain edges, steps, defects, microcracks and inclusions, resulting in the formation of etch pits. Massive morphology particles exhibited the greatest density of crystalline defect, and had the greatest rate of oxidation.

Effective mineral classification, particle morphology identification and observation of mineral weathering processes were accomplished by scanning electron microscopy, demonstrating the need for assessment of sulfide mineral weathering characteristics for effective remediation of sites impacted by mining.

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INTRODUCTION

Sulfide minerals are commonly present in mining environments. Pyrite is the most common sulfide mineral and occurs in association with hardrock mineral assemblages and in depositional sedimentary environments. The oxidation of sulfide minerals, dominantly pyrite, has been implicated in the generation of acid upon mineral dissolution in the presence of oxygen and water. The generation of acid as a consequence of sulfide mineral oxidation is responsible for the degradation of thousands of miles of surface water streams, and tens of thousands of acres of land.

Analysis of pyritic mine wastes is consequently very important to understanding the postmine effects of waste material oxidation. Net potential acidity is typically estimated by laboratory determination of the sample sulfur content attributed to pyrite though field observation of the consequences of acid generation suggest that great variation occurs in the *rate* of pyrite oxidation.

The influence of sulfide particle size and morphology may be an important mineral physical property pertaining to the rate of sulfide mineral oxidation. The importance of total sulfide mineral surface area (Wiersma and Rimstidt 1984) has been implicated in the rate of mineral oxidation (Pugh et al. 1984), though mineral surface area alone is an insufficient method of estimating the rate of sulfide mineral oxidation. The morphology of sulfide particles found in mining environments may exert a fundamental influence on the rate of oxidation in addition to surface area (Jennings and Dollhopf 1992).

Pyrite is found in mining environments in many crystal forms as the dominant sulfide mineral, where crystal morphological characteristics are controlled by the environment of formation. Though great variation exists in pyrite particle morphology (Grady 1977), three general classes of particle morphology were identified: euhedral, massive and framboidal. Euhedral particles are well formed crystals of regular atomic arrangement, typically found in hardrock mining environments. Massive particles are noncrystalline masses of mineral matter lacking regular atomic arrangement. Framboidal particles are a unique morphological class of spherical aggregates of crystalline pyrite typically less than 25 μm in diameter.

In this investigation, sulfide particles of different morphology from dissimilar mine environments were related to the acid generation ability of each morphological type by particle size. Sulfide minerals were submitted to oxidation by 10% H_2O_2 to assess the influence of particle size and morphology on rate of acid generation. The evolution of chemicals in the resulting leachate was measured, and surface mineral dissolution behavior documented by scanning electron microscopy.

WEATHERABILITY OF SULFIDE MINERALS BY OXIDATION WITH HYDROGEN PEROXIDE

The weathering of pyrite by oxygen and water is presented in Reaction 1,

$$FeS_2 + \frac{15}{4} O_2 + \frac{7}{2} H_2O = Fe(OH)_3 + 2\,SO_4^{2-} + 4\,H^+ \qquad [1]$$

where the solid mineral phase is oxidized, resulting in acid formation.

The simulation of natural weathering in the laboratory by H_2O in the presence of O_2 has been attempted with limited success. The great length of time required to attain a laboratory response to H_2O/O_2 weathering limits the practicality of water weathering tests for assessment of acid generation. Hydrogen peroxide is a stronger oxidizer than the H_2O/O_2 redox pair, so rapid characterization of potentially acid producing samples can be accomplished (O'Shay et al. 1990) (Reaction 2). The weathering of sulfides by hydrogen peroxide accentuates the differences between samples when compared to H_2O weathering, and facilitates the understanding of acid generation principles.

$$FeS_2 + \frac{15}{2} H_2O_2 = Fe(OH)_3 + 2SO_4^{2-} + 4H^+ + 4H_2O \qquad [2]$$

High graded sulfide minerals, dominantly pyrite, were subjected to oxidation by 10% H_2O_2 under laboratory conditions. The evolution of chemical constituents to the resulting leachate was recorded in parallel with the mass removed during oxidation. All leachate parameters (pH, electrical conductivity, iron, sulfate, and titratable acidity) as well as mass loss and reaction time parameters were recorded by sample source and particle size. The dominant crystal morphology of each sample was recorded for each sample. Four particle size fractions were used consistently, >250 μm, 106-250 μm, 38-106 μm and <38 μm. Wherever sufficient sample material was available, three replications were performed for each sample by particle size class.

RESPONSE OF SULFIDE MINERALS TO H_2O_2 WEATHERING

The morphology of the sulfide particles from each sample source exerted a fundamental influence on the response to oxidation. Table 1 further details the importance of particle morphology on generation of acidic conditions.

Table 1. Summary of response to oxidation by 10% H_2O_2 by crystal morphology.

			Response Variable (Mean of All Measurements)					
Particle Size Fraction (μm)	Dominant Crystal$^{\blacktriangle}$ Morphology	Mass Loss (%)	EC (dS m^{-1})	Titratable Acidity (mg $CaCO_3$ l^{-1})	SO_4^{2-} (mg l^{-1})	Fe (mg l^{-1})	pH	Reaction Time (Days)
> 250	Euhedral$^{1/}$	-7.01$^{+\S}$ a	4.96 a	2330 a	2282 a	657 a	2.21 a	0.83 ab^{++}
> 250	Massive$^{2/}$	-59.95 B$^{\bullet}$	34.65 A	20870 B	20040 B	5805 B	1.44 A	1.00 B^{++}
106-250	Euhedral	-9.60 a	6.42 a	3164 a	3129 a	931 a	2.09 a	0.89 b^{++}
106-250	Massive	-53.59 B	30.65 A	18450 AB	18170 B	5201 B	1.46 A	0.89 AB^{++}
38-106	Euhedral	-9.45 a	6.22 a	3284 a	3078 a	968 a	2.07 a	0.41 ab
38-106	Massive	-50.40 B	29.12 A	17400 AB	16750 AB	4964 B	1.48 A	0.89 AB
< 38	Euhedral	-8.34 a	5.90 a	2827 a	2787 a	832 a	2.06 a	0.28 a^{++}
< 38	Massive	-29.78 A	23.08 A	11670 A	10390 A	2725 A	1.48 A	0.52 A^{++}
Mean of All Particle Size Fractions	Euhedral	-8.60	5.87	2901	2819	847	2.11	0.60^{++}
	Massive	-48.43	29.38	17100	16340	4675	1.46	0.83^{++}

[•] Massive means in the same *column* followed by the same *uppercase* letter are not significantly different ($p \leq 0.05$).

[§] Euhedral means in the same *column* followed by the same *lowercase* letter are not significantly different ($p \leq 0.05$).

[+] Euhedral and massive means are significantly different ($p \leq 0.05$) within each size fraction for each response variable except where denoted by $^{++}$ where massive and euhedral means are not significantly different ($p \leq 0.05$).

[1/] N = 24 observations for all euhedral means.

[2/] N = 23 observations for all massive means.

[▲] Samples containing waste sulfide minerals were obtained from 13 operational coal and hardrock mines in the western U.S., pyrite was the dominant sulfide mineral in 12 of 13 samples.

Particle morphology, as distinguished between the two broad classes massive and euhedral, is a very important consideration in the classification of the acid producing potential of sulfides, dominantly as pyrite. Within each size fraction, >250 μm, 106-250 μm, 38-106 μm and <38 μm, for each of seven different response variables, *the massive and euhedral morphology samples are significantly different ($p \leq 0.05$) for every comparison* except reaction time. The differences between massive and euhedral morphology samples are prominent.

Comparing the titratable acidity of massive and euhedral particle morphologies in the >250 μm size fraction (Table 1), the euhedral morphology samples generated a mean 2330 mg $CaCO_3$ l^{-1} titratable acidity while the massive morphology samples generated a mean 20870 mg $CaCO_3$ l^{-1}, a nearly 10 fold difference. Taking a different comparison, in the 38-106 μm size fraction the mean electrical conductivity of the euhedral morphology samples was 6.22 dS m^{-1} while the massive morphology mean electrical conductivity was 29.12 dS m^{-1}. The leachate chemistry results demonstrate large differences in mineral response to oxidation.

The reason for dissimilar oxidation between euhedral and massive morphology particles is attributed to differences in the atomic structure of the crystals. Since massive particles are amorphous and noncrystalline, the iron and sulfur atoms are not located in a regular crystalline lattice as they are in euhedral particles. Since the massive particles do not have continuous regular crystalline structure, the iron and sulfur electrons are not shared uniformly through the crystalline structure. The presence of irregular electron distribution, or 'loose electrons', provide many sites on massive particles for attack and removal of the crystal by oxidation. Euhedral particles can also have defects in the crystalline structure which becomes sites of excess energy and sites which become the focus of oxidation, but the frequency of imperfection in euhedral particles is small compared to massive particles. *The reactivity of massive morphology pyrite to oxidation is subsequently a consequence of the atomic structure of the crystal,* which is characteristic to the specific environment of formation. Therefore, characterization of the acid generation potential of a sample by acid-base account analysis would identify the quantity of the sulfur component present as pyrite, but would fall short of understanding the acid generation potential of the sample since no assessment of particle morphology would be made.

SEM/EDAX EXAMINATION OF WEATHERABILITY OF DIFFERENT PYRITE MORPHOLOGIES

The most revealing evidence pertaining the dissolution of pyrite, and resulting surface morphologies, by hydrogen peroxide was obtained by the Scanning Electron Microscopy (SEM). Pyrite particles were cast in an epoxy mold, photographed, treated with hydrogen peroxide and photographed a second time, locating the same particles before and after oxidation to compare surface weathering features.

After casting pyrite particles from different geologic sources in a single epoxy mold, the casting was sanded with progressively finer sandpaper until smooth, fresh, unoxidized mineral surfaces were evident. Figure 1 illustrates a pyrite particle cast in epoxy prior to treatment with hydrogen peroxide. The dark material containing large air bubbles is the epoxy. The pyrite particles are

Figure 1. High reactive surface area euhedral morphology pyrite particles (1000 μm) cast in epoxy prior to oxidation (45X magnification).

approximately 1 mm (1000 μm) in diameter, euhedral morphology particles, containing crystalline imperfections (microcracks and small pits). Figure 2 displays the same particles after oxidation by 2 ml 30% H_2O_2 for 45 minutes.

The destructive removal of mass from the sample is clearly demonstrated by Figure 2. The removal of mass did not occur uniformly across the mineral surface, rather mass removal was focused at sites containing crystalline imperfection. The mineral microcracks evident before oxidation, became fissures during oxidation and the small pits prior to oxidation became large etch pits during oxidation. While mass was destructively removed from portions of the crystal containing imperfections, regions of the mineral surface lacking imperfection were relatively unaltered. Further detail of the mineral surface where aggressive attack of the mineral occurred is presented in Figure 3, demonstrating the depth of mineral dissolution. Defects in the crystalline structure of the mineral are distributed throughout the entire crystal, so though oxidation is initiated on the crystal surface the process of oxidation can rapidly penetrate into the particle. Though much attention has been paid to the surface area of pyrite as it pertains to the generation of acidic drainage, the implication from Figures 2 and 3 is that the

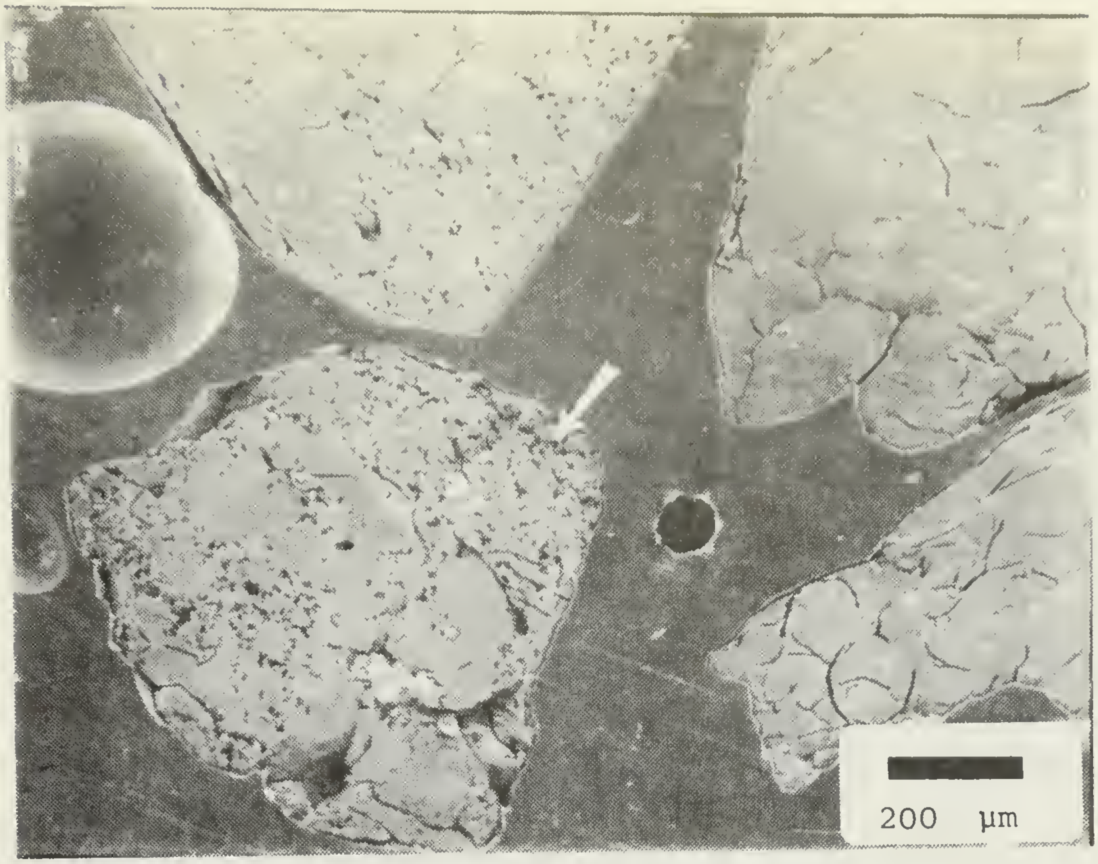

Figure 2. High reactive surface area euhedral morphology pyrite particles (1000 μm) cast in epoxy after oxidation by 30% H_2O_2 (45X magnification). White arrow indicates location of Figure 3.

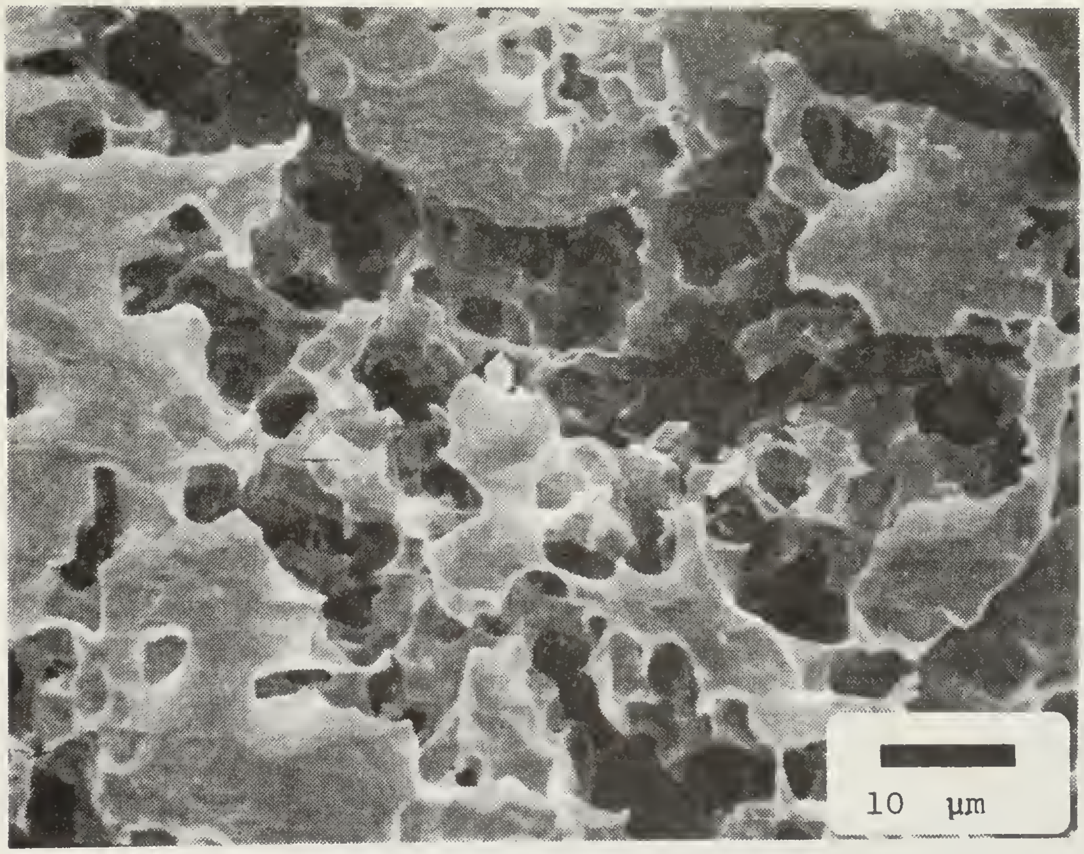

Figure 3. Pyrite surface morphology (from Figure 2, see arrow) after exposure to 30% H_2O_2 demonstrating innerpenetrating destructive removal of mineral material (630X magnification).

reactive exposed surface area may exert a stronger influence on the generation of acid than the total exposed surface area. The reactive surface area is defined as the surface area which is readily chemically reactive to oxidation. Potentially, the reactive surface area is the dominant control on generation of acidic drainage by pyrite oxidation.

By contrast, Figures 4 and 5 are SEM photographs taken before and after oxidation by 30% H_2O_2 of euhedral pyrite derived from a different environment. The treatment of the pyrite samples in Figures 2 and 5 was identical, since both samples were in contact with the same 2 ml 30% H_2O_2 for the same interval of time. The response of the pyrite particles in Figure 5 was markedly less than the response of the particles in Figure 2. The total surface area of the pyrite particles in Figures 1 and 4 was not measured, but the particles are all approximately 1000 μm in diameter. The reactive surface area was not quantified for either of the sample sources, but Figures 2 and 5 suggest that the difference in reactive surface between the two sources is distinct. The low reactive surface area euhedral morphology pyrite (Figure 5) is comprised of crystals relatively free from defects or microcracks which were exploited by oxidation in the high reactive surface area euhedral morphology pyrite in Figure 2.

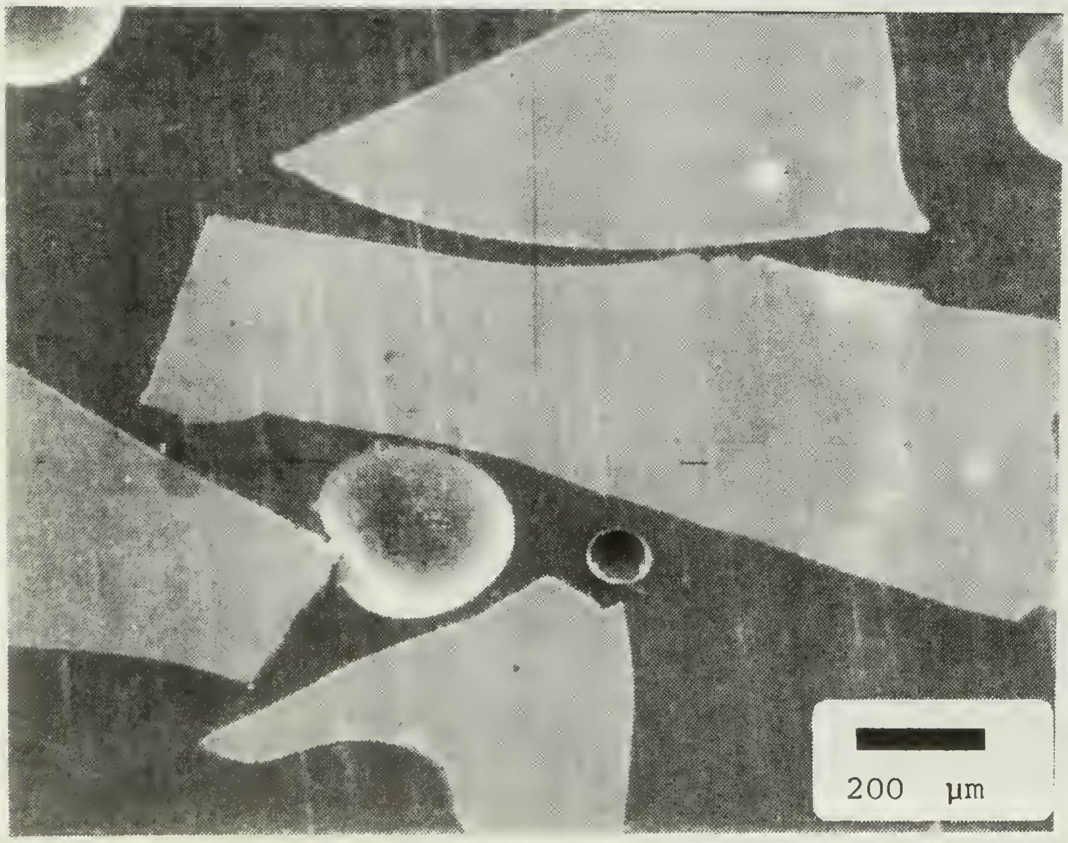

Figure 4. Low reactive surface area euhedral morphology pyrite particles (1000 μm) cast in epoxy prior to oxidation (45X magnification).

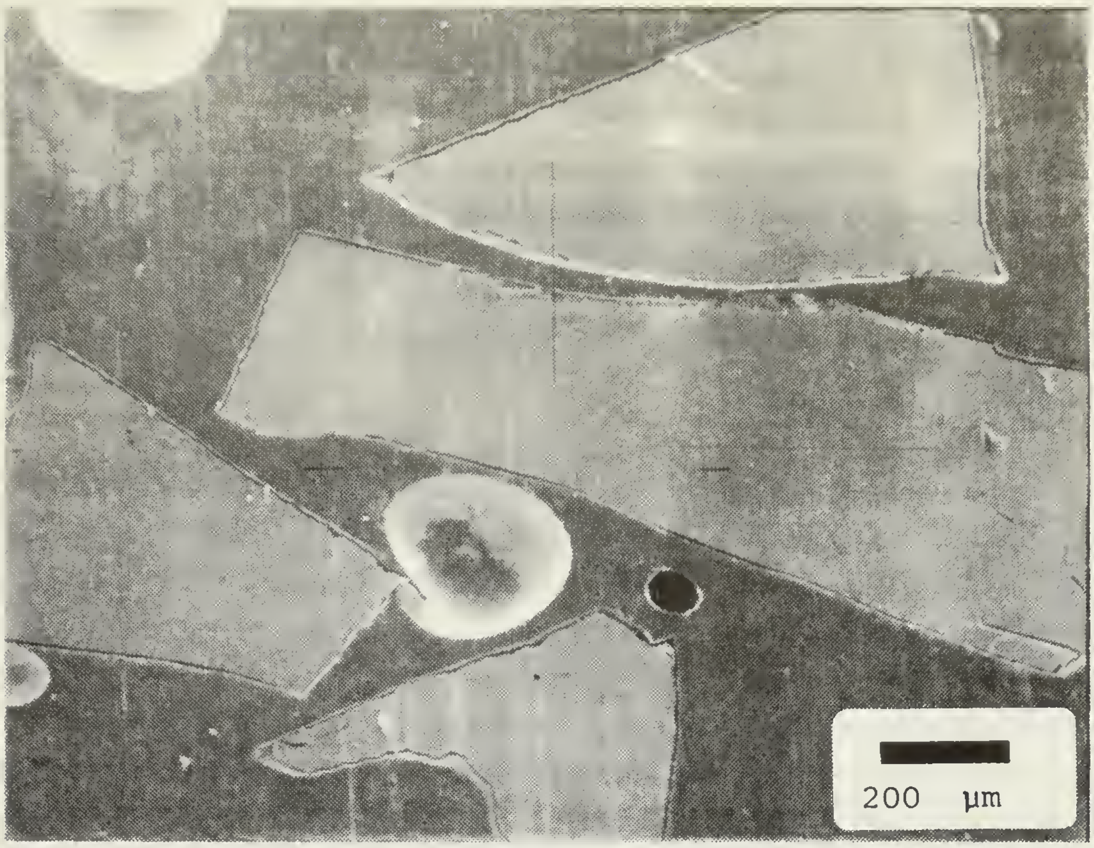

Figure 5. Low reactive surface area euhedral morphology pyrite particles (1000 μm) cast in epoxy after oxidation by 30% H_2O_2 (45X magnification).

CONCLUSIONS

Particle morphology, whether massive or euhedral, exerted the dominant control on sulfide oxidation, while particle size influenced the rate of oxidation to a lesser degree. The process of sulfide mineral dissolution occurred at focused locations on the mineral surface where imperfections in the crystalline structure occurred. The development of crystalline imperfection was a consequence of the unique environment of formation and the thermodynamic and geochemical setting at the time of formation of the mineral. Locations where oxidation was initiated included cleavage planes, steps, fractures, dislocations, inclusion and defects. The result of oxidation at these reactive sites on the surface of the mineral was the formation of an etch pit. The frequency of etch pit formation was a function of the density of defects on the surface of the mineral. Since particles with massive morphology lack regular crystalline structure they are defect laden and have many sites for attack by oxidizing agents. Sulfide particles with euhedral morphology typically exhibit defects in the crystalline structure, but many fewer than the particles with massive structure. The relative ease of oxidation of the sulfide particles at any location is a function of the geologic history, and characteristic physical properties of the sulfides inherent to the specific location.

The oxidation of sulfide minerals was recorded for each of four distinct size fractions to assess the importance of particle size to the generation of acid. Particles of smaller size have greater surface area per mass than larger particles, therefore, potentially greater acid generation might be expected from the smaller size particles. The result of experimentation revealed that in fact the smallest size fraction was the *least* acid producing, and particle morphology exerted the dominant influence on rate of acid generation. The *reactive* surface area, meaning surface area containing imperfections in the crystalline structure, is more important than the *total* surface area.

The implication to remediation of sites containing sulfide minerals, is that though a laboratory analysis of acid-base account provides an estimate of the total potential acidity in a sample, no knowledge of the rate of oxidation is implied. The result of the oxidation of pyrite samples from different geological environment of the same particle size, was the generation of acidity which varied by an order of magnitude between samples. A mining environment dominated by euhedral sulfide morphology may require decades or centuries of time to impact site acidity. However, a mining environment dominated by a massive sulfide morphology may reveal acid remediation problems in a much shorter timeframe. The ultimate generation of acidity from 1.000 gram of *massive* pyrite will be the same as the acidity generated by oxidation of 1.000 gram of *euhedral* pyrite, but the rate of dissolution may be very dissimilar. The acid load to surface water resources or impact to plant growth may be entirely a function of the rate of oxidation. If oxidation should proceed rapidly, negative environmental consequence may accrue, while if the oxidation of sulfides occurs slowly, the addition of acid load may be diluted to the point where aquatic or vegetative mortality does not occur. Remediation of sulfide containing environments should therefore reflect knowledge of the differential weathering characteristics of pyrite of varying morphology.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

DEEP LIME INCORPORATION METHODS FOR NEUTRALIZATION OF ACIDIC MINESOILS[1]

Douglas J. Dollhopf[2]

ABSTRACT

The purpose of this investigation was to develop new equipment for neutralizing acidic minesoils to the 120 cm depth. Lime slurry pressure injection (LSPI) equipment developed in this study significantly increased the mean pH of coal waste from 2.5 to 6.7, and 82% of the profile (0-120 cm) had a pH greater than 5.5, a level considered suitable for plant growth. After three growing seasons, plant production on LSPI treated areas was significantly greater compared to a control and a limestone treatment incorporated to the 30 cm depth. Minesoils can be treated with LSPI at a rate of 0.05 ha/hr/120 cm depth.

A moldboard plow designed for tillage to the 120 cm depth was fitted with a lime slurry application system. A field test indicated this plow significantly increased the mean pH of the 0-120 cm deep spoil profile from 3.0 to 6.3. The plow is capable of treating minesoils at the rate of approximately 0.3 ha/hr/120 cm depth.

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INTRODUCTION

Thousands of abandoned and active mine sites in the United States must be amended with lime to control acid minesoil problems that limit revegetation. Acidic mine lands addressed by the Abandoned Mine Reclamation Program are generally remediated with limestone incorporated with locally available agricultural tillage equipment. There is concern that acidic minesoils amended to only the 15 to 30 cm depth with agricultural tillage equipment may not provide sufficient root zone for either optimum plant growth or long-term plant establishment. Dollhopf (1992) demonstrated that agricultural discs, chisel plows (subsoilers), and moldboard plows can incorporate lime to only the 30 cm depth. Field tests with static and vibratory ripper shanks set at the 84 to 100 cm depths resulted in lime incorporation to the 9 to 35 cm depth (Dollhopf 1992).

It is a long established soil science principle that applied lime essentially does not migrate deeper into a profile. Metzger (1934) and Brown and Munsell (1938) reported that 10 to 14 years were required for surface applied lime to increase the soil pH to a 15 cm depth. Since lime moves slowly in the soil profile, it is beneficial only in the immediate vicinity of application. Equipment is needed that can incorporate lime thoroughly and deep into acidic minesoil profiles to assure successful long-term plant growth.

The Surface Mining Control and Reclamation Act (1977) indicates all acid-forming mine waste must be covered with a material to achieve an ecologically sound land use (Section 515(b)(3)). Likewise, the Code of Federal Regulations (Office of Federal Register 1985) indicates acid materials exposed or produced during mining shall be adequately covered with nontoxic material, *or treated,* to minimize adverse effects on plant growth (CFR 816.102(f)). In order to meet the intent of these regulations, states generally require that 120 cm of nonacidic and nontoxic material be available for plant growth. Therefore, when acidic materials appear at the spoil backfill surface, they must be removed or amended to the 120 cm depth.

The purpose of this investigation was to develop new equipment approaches for neutralizing acidic minesoils to the 120 cm depth. Specific objectives were to:

- develop and evaluate a lime slurry pressure injection system capable of treating minesoils to the 120 cm depth;
- develop and evaluate a moldboard plow capable of tillage to the 120 cm depth and equipped with a lime slurry pressure application system; and
- compare plant response on acidic minesoils limed to the 120 cm and 30 cm depths.

REMEDIATION OF ACID MINESOILS WITH LIME SLURRY PRESSURE INJECTION

Technical Approach

A slurry composed of 400 g $Ca(OH)_2$ per liter of water was mixed on site in a portable tank and was pumped directly into steel injector rods (Figures 1 and 2). Hollow stem injection rods were pushed hydraulically into the ground to predetermined depths. The injection rod tip is perforated so that lime slurry was released under a pressure of 3.5 to 14 kg/cm^2 (50-200 $pounds/in^2$) into soil voids. Slurry was injected until it was rejected and forced out at the soil surface indicating the depth increment was saturated. The result was a slurry that penetrated the cracks, fissures, and pores of the soil. The injection rod was raised or lowered to treat an entire profile.

The pH of a $Ca(OH)_2$ slurry is approximately 12.5. When the slurry is first applied to acid minesoils, the soil pH is typically between 9 and 12.5. Therefore, the minesoil pH is not suitable for plant growth. Three to 12 months of time may be required for the $Ca(OH)_2$ to transform to $CaCO_3$ which will yield a minesoil pH less than 8.5.

A randomized block experimental design consisting of five treatments (Table 1) was implemented on acidic (pH 2.9) coal waste materials in Texas. A description of liming rates and materials used, minesoil physicochemical characteristics, minesoil sampling and analysis methods, plant materials seeded, plant growth measurement methods, and root distribution measurement methods are presented in detail elsewhere (Dollhopf 1992).

Table 1. Treatments implemented into a randomized block experimental design.

Plot Number	Treatment
1	Control
2	Standard - $CaCO_3$ incorporated to 30 cm with tillage equipment
3	Hot slaked $Ca(OH)_2$ injected to 120 cm depth, 150 cm spacings
4	Hot slaked $Ca(OH)_2$ injected to 120 cm depth, 75 cm spacings
5	50% hot slaked $Ca(OH)_2$ + 50% $CaCO_3$ injected to 120 cm depth, 75 cm spacings

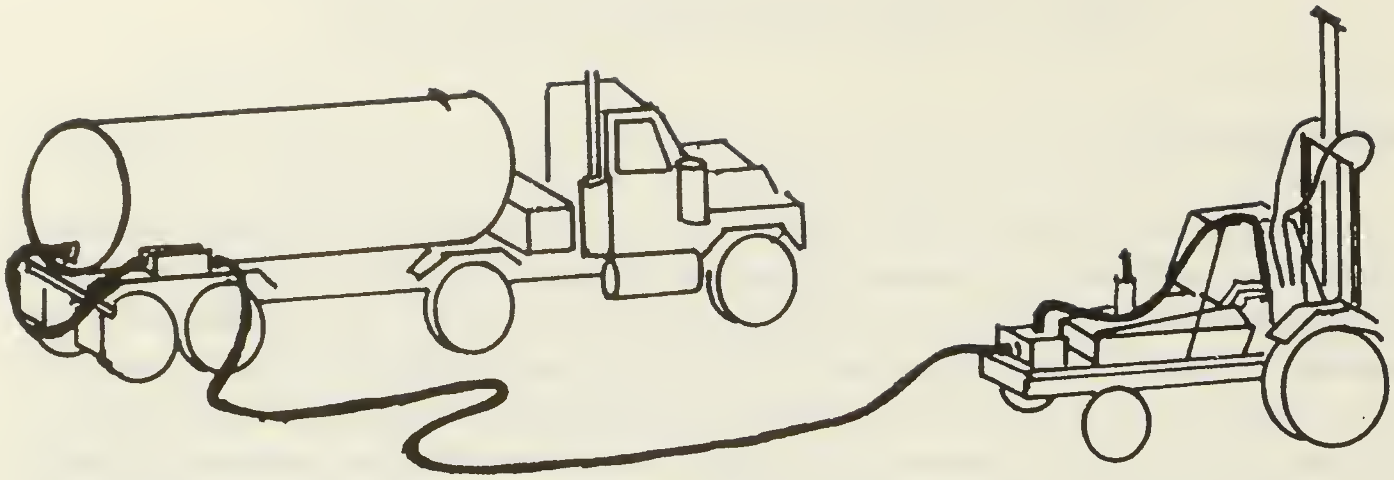

Figure 1. Illustration of slurry tank truck and injection tractor used to amend acid minesoils to the 120 cm depth.

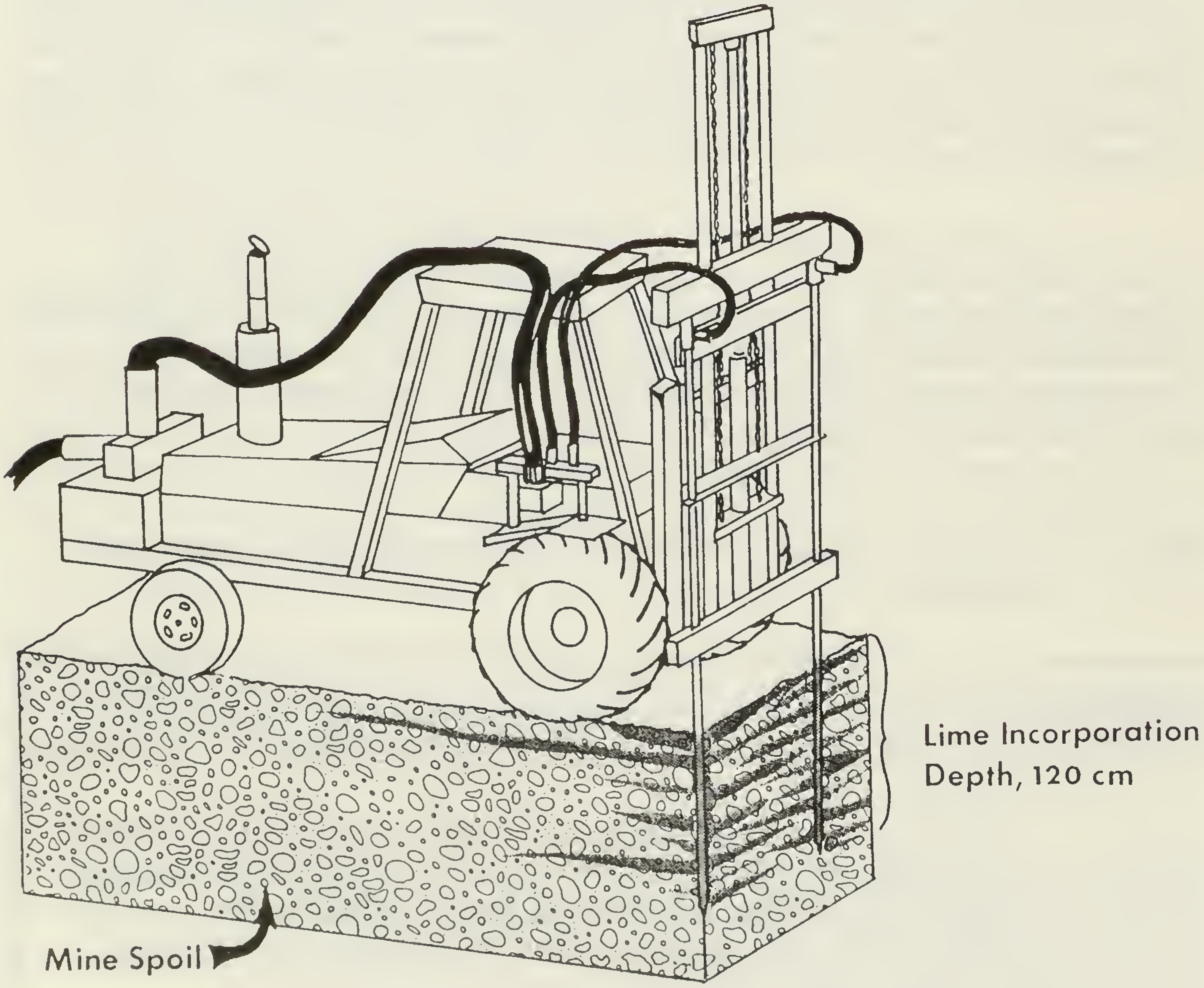

Figure 2. Diagram of the lime slurry injection tractor used to treat acid coal waste in Texas.

LSPI Effect on Minesoil pH

Prior to amendment application, the mean pH of this coal waste material was 2.47 across all plots and depths. There were no significant differences in pH between depth increments or between test plot areas. After LSPI with $Ca(OH)_2$ injected every 150 cm across the minesoil, 62% of the 120 cm deep profile had a significantly greater pH compared to the control (Table 2). The pH of the 60 to 105 cm increment was not significantly different compared to the control and averaged 4.36 which would not be suitable for plant growth.

After LSPI with $Ca(OH)_2$ injected every 75 cm across the surface to the 120 cm depth, 92% of the minesoil profile had a pH significantly greater compared to the control and averaged 6.69. These results indicate a 75 cm LSPI spacing in minesoils is adequate to amend a pH problem, but not a 150 cm LSPI spacing.

Table 2. Coal waste profile pH *two months after* amendment application.

Profile Depth (cm)	Control	$CaCO_3$ Incorporated 30 cm	$Ca(OH)_2$ LSPI[△] to 120 cm Depth, 150 cm Spacings	$Ca(OH)_2$ LSPI to 120 cm Depth, 75 cm Spacings	50% $Ca(OH)_2$, 50% $CaCO_3$ LSPI to 120 cm Depth, 75 cm Spacings
0-10	2.87 a[†‡]	7.40 c	8.86 cd	6.21 b	7.80 bc
10-20	2.82 a	4.96 b	5.41 b	5.84 b	4.51 b
20-30	2.74 a	4.43 ab	6.35 b	4.48 ab	4.55 ab
30-45	2.79 a	2.52 a	5.84 bc	7.19 c	5.11 b
45-60	2.94 a	2.56 a	5.18 b	6.45 b	4.72 ab
60-75	2.87 a	2.50 a	4.50 ab	5.55 b	4.16 ab
75-90	3.08 a	2.58 a	4.02 a	6.21 b	4.39 ab
90-105	3.10 a	2.59 a	4.57 ab	7.51 c	5.09 b
105-120	3.08 a	2.68 a	5.19 b	5.57 b	5.77 b

[△] LSPI = Lime Slurry Pressure Injection.

[†] Means followed by the same letter in the same row are not significantly different (probability = 0.05).

[‡] Sample size varies as follows: number of samples = 9 for the control and the $CaCO_3$ incorporated to 30 cm treatment; number of samples = 3 for the last six depths of the $CaCO_3$ incorporated to 30 cm treatment; number of samples = 27 for the LSPI treatments.

Following LSPI with the 50/50 mix of $Ca(OH)_2$ and $CaCO_3$ to the 120 cm depth, approximately half (54%) of the profile had a pH significantly greater compared to the control (Table 2). These results indicate the use of $CaCO_3$ in the slurry may have decreased the mobility of the amendment to permeate soil pores since the use of only $Ca(OH)_2$ in the slurry, and same injection spacing, was more effective in increasing the soil pH.

Application of $CaCO_3$ to the minesoil surface followed by tillage to the 30 cm depth resulted in the pH being significantly increased to only the 20 cm depth, and the pH of the 10 to 20 cm increment was only 4.96 (Table 2). These results are typical for limestone incorporation with standard agricultural tillage equipment.

LSPI Effect on Plant Performance

After three growing seasons, the LSPI treatment using $Ca(OH)_2$ with 75 cm spacings had a significantly greater plant canopy cover compared to the other two LSPI treatments (Table 3). Although plant canopy cover was numerically greater for the $Ca(OH)_2$ LSPI treatment (75 cm spacing) compared to $CaCO_3$ incorporated to 30 cm, this difference was not significant.

Plant production on the $Ca(OH)_2$ LSPI treatment (75 cm spacing) was significantly greater compared to all other treatments after three growing seasons (Table 3). Minesoil profile pH data were not collected in 1991, but presumably all $Ca(OH)_2$ applied to these test plots would have weathered to $CaCO_3$ and plant growth problems associated with pH levels greater than 8.5 would not be present.

Maximum rooting depth for each treatment was near the depth planned for amendment incorporation. All LSPI treatments permitted significantly deeper plant root growth compared to surface applied $CaCO_3$ tilled to the 30 cm minesoil depth.

DEVELOPMENT OF A LIME SLURRY PLOW TO AMEND ACID MINESOILS TO THE 120 CM DEPTH

Technical Background

A 120 cm Post Brothers plow (Figure 3) was retrofitted with a lime slurry application system. The slurry application unit consisted of a 1.2 m long by 15.2 cm outside diameter manifold pipe. This manifold fed slurry to two 2.4 m long by 7.6 cm outside diameter spreader pipes equipped with numerous ball valves to release slurry (Figure 4). Each spreader pipe contained ten 2.54 cm ball valves that were adjustable pertaining to slurry release direction and flow rate. This

Table 3. Canopy cover and aboveground biomass production in the third growing season, 1991.

Plant Species or Group	Control	$CaCO_3$ Incorporated 30 cm	$Ca(OH)_2$ LSPI[△] to 120 cm Depth, 150 cm Spacing	$Ca(OH)_2$ LSPI to 120 cm Depth, 75 cm Spacing	50% $Ca(OH)_2$, 50% $CaCO_3$ LSPI to 120 cm Depth, 75 cm Spacing
CANOPY COVER, %					
Eragrostis superba	0	11.1[†]	7.3	17.4	12.1
Dichanthium annulatum	0	10.6	10.1	18.2	8.7
Panicum coloratum	0	17.2	7.9	13.1	10.2
Kochia scoparia	0	1.3	0	0	0
Total Perennial Grasses	0 a	38.9 cd	25.3 b	48.7 d	31.0 bc
Total Weeds	0 a	1.3 b	0 a	0 a	0 a
Total Vegetation	0 a	40.2 cd	25.3 b	48.7 d	31.0 bc
ABOVEGROUND BIOMASS PRODUCTION, KG/HA, DRY WEIGHT					
Grasses	0 a	512[‡] b	374 b	721 c	465 b
Weeds	0 a	21 b	0 a	0 a	0 a
Total Vegetation	0 a	533 b	374 c	721 d	465 bc

[△] LSPI = Lime Slurry Pressure Injection.

[†] Mean of 30 samples.

[‡] Mean of 15 samples.

$ Means within the same row are not significantly different when followed by the same letter (probability = 0.05).

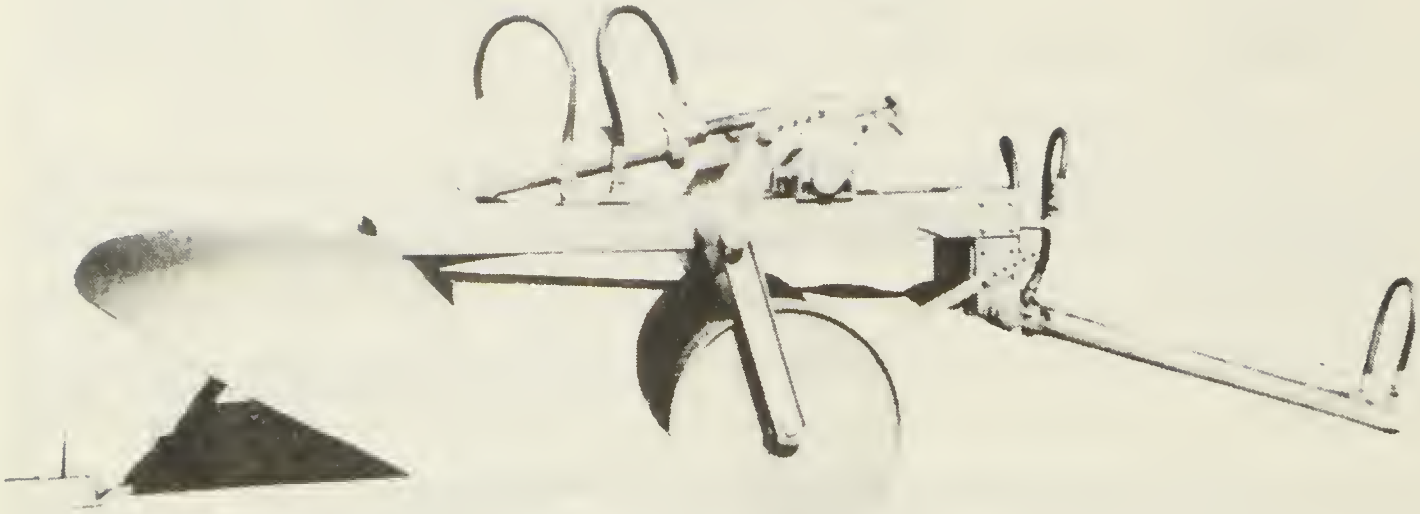

Figure 3. Side view of Post Brothers 120 cm plow.

Figure 4. Post Brothers plow working at the 120 cm spoil depth and fitted with lime slurry application equipment.

manifold and piping was arc-welded to the plow center beam and forward of the moldboard plow blade. Construction and installation of the slurry applicator system cost approximately $2,100. A Post Brothers plow capable of tillage to the 120 cm depth costs approximately $60,000. Lime slurry was mixed in an 18,925 L tank truck. A 10.16 cm diameter pump on the truck had the capacity to deliver 1703 L/minute (450 gal/min) at a pressure of 0.9 kg/cm^2 (13 pounds/in^2) through a 5 cm outside diameter hose connected to the manifold on the plow. The tanker truck traveled adjacent to the plow during slurry application.

The lime slurry plow was tested on a 9 m by 25 m abandoned mineland site in Texas. This acidic (pH 3.0) minesoil had a total lime requirement (i.e. exchangeable + potential) of 503 T $CaCO_3$/ha/120 cm depth (208 T/acre/4 ft). Minesoil sampling and analysis procedures are presented in detail elsewhere (Dollhopf 1992).

Performance of the Lime Slurry Plow

The pH of the spoil materials was significantly increased throughout the 0-120 cm profile after lime slurry was applied in conjunction with the 120 cm plow (Table 4). As shown in Table 4, the mean pH was increased from 3.02 to 6.27 in the 0-120 cm spoil profile, and 66% (1 std. dev.) of the post-treatment soil increments had a pH between 5.59 and 6.95. In the 0-30 cm spoil zone, the mean pH was significantly increased from 2.68 to 6.56 and 95% (2 std. dev.) of the post-treatment spoil increments had a pH greater than 5.48. In the 30-60 cm spoil zone, the mean pH was significantly increased from 2.66 to 6.50 and 95% of the spoil increments had a pH greater than 5.94. In the 60-90 cm spoil zone, the mean pH was significantly increased from 3.11 to 6.36 and 83% of the treated spoil had a pH greater than 5.5. In the 90-120 cm spoil zone, the mean pH was significantly increased from 3.63 to 5.68 and, 54% of these increments had a pH greater than 5.5. After treatment, spoil increments rarely (2%) fell below a pH of 5. These results are consistent with field observations that indicated the four foot plow exposed the upper portion of the spoil profile to lime slurry more efficiently than deeper material. The upper portion of the profile tended to cave downward and into deeper material, thereby decreasing the opportunity for slurry application into deep materials.

CONCLUSIONS

Using proper technique, the LSPI method is an effective procedure for amending acidic conditions to the 120 cm minesoil depth and probably much deeper. Approximately 0.05 ha/hr (0.12 ac/hr) of land can be treated with LSPI. This technique may be particularly suitable for small areas where reclamation/revegetation failed and the area must be amended to the 120 cm depth with minimal disturbance to adjacent areas. Several contractors in the United States can provide LSPI services.

Table 4. Spoil profile pH before and after lime slurry application in combination with a four foot plow.

Spoil Increment	**Sample Number**	**pH**		
		Mean ± Std. Dev.	**Maximum**	**Minimum**
0-120 cm				
Before Liming	96	3.02 ± 0.68 a[+]	5.77	2.16
After Liming	96	6.27 ± 0.68 b	8.44	4.89
0-30 cm				
Before Liming	24	2.68 ± 0.22 a	3.05	2.28
After Liming	24	6.56 ± 0.54 b	8.44	6.12
30-60 cm				
Before Liming	24	2.66 ± 0.28 a	3.17	2.16
After Liming	24	6.50 ± 0.28 b	7.44	6.05
60-90 cm				
Before Liming	24	3.11 ± 0.47 a	4.26	2.25
After Liming	24	6.36 ± 0.87 b	8.30	5.10
90-120 cm				
Before Liming	24	3.63 ± 0.97 a	5.77	2.52
After Liming	24	5.68 ± 0.57 b	6.96	4.89

[+] Means within each depth increment followed by the same letter are not significantly different (probability = .0001) using the paired t-test.

The application of lime slurry in combination with a 120 cm deep moldboard plow was an effective method for neutralization of acidic spoils. Production measurements collected during the field test indicated approximately 0.3 hectares of mine spoil could be treated per hour with the lime slurry plow. Therefore, this method would be suitable for amending large areas of acidic materials.

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Billings Symposium, 1993

PHYSICAL PROPERTIES OF SOILS CONTAINING COAL

P. P. Sharma[1], F. S. Carter, and G. A. Halvorson

ABSTRACT

Besides primary particles of sand, silt, clay and rock fragments, some mineland soil profiles in west-central North Dakota also contain lignite coal fragments. This study was conducted to determine soil water retention and other physical properties of soil mixed with coal fragments. Two types of coal samples, one commercial lignite with high water repellency and the other a degraded lignite with low water repellency, were mixed with a sandy loam, a loam, and a sodic silty clay loam soil sample in the laboratory. The analyses of water content, bulk density, particle density, and soil water retention characteristics versus coal content data suggest that these properties can be predicted by linear interpolation of the properties of component soil and coal samples.

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INTRODUCTION

Success of revegetation programs after reclamation of surface coal minelands in the semi-arid climate of the Northern Great Plains depends upon the amount of water available for plant growth. Beside climatic factors akin to a semi-arid environment, experiments in mineland reclamation in North Dakota have recognized that status of soil water depends on the landscape position (Halvorson and Doll 1991) and thickness and characteristics of topsoil and subsoil materials (Schroeder and Bauer 1984).

Besides primary particles of sand, silt, clay and rock fragments, mineland soil profiles at some locations contain considerable amounts of coal fragments ranging in size from less than 1 mm (fine-sand size) to about 300 mm (stone size) or more. The presence of coal is usually localized with high amounts occurring in the vicinity of excavated coal pits, coal hauling routes and temporary surface storage sites. When soils from these areas are respread during the reclamation process, considerable amounts of coal fragments are distributed within the root zone.

Presence of a lignite layer in the root zone impedes root growth and water movement through the layer due probably to high water repellency of lignite (Richardson and Wollenhaupt 1983). Field assessment of soil water by neutron probes show high readings due to presence of lignite coal in the vicinity of access tubes (personal observation). After making corrections for the H content of lignite (Halvorson 1986), the water contents of soils with coal are still higher than surrounding soils without coal. Information on the mobility of this coal-water either through extraction by plant roots or through redistribution to surrounding soil is not available. The objective of this study was to obtain preliminary estimates of water retention and other properties of soils containing coal.

METHODS AND MATERIALS

Two coal samples, one a commercial lignite and the other a partially degraded lignite were mixed with three soil samples collected from minelands of the BNI Coal Co., at Center, North Dakota. Sample descriptions, preparations, mixing procedures, and the methodology used for determinations of particle size distribution, bulk density, particle density, water repellency, and soil water retention characteristics are described in detail by Sharma et al (1993). In summary, bulk soil-coal mixtures of 5, 10, 15, 25 and 50 % coal by oven-dry weight were used in the experiment. Subsamples of each component were used to determine particle density, major cations, and water repellency index (WRI). Subsamples of each component and the soil-coal mixtures were used to determine water contents at saturation and at various desorption pressures.

The measured water contents (ω, kg/kg) versus pressure head (h, kPa) data of each component sample were fitted with a soil water retention curve represented by a two parameter empirical equation (van Genuchten 1980).

$$\omega = \omega_{15} + (\omega_o - \omega_{15})\,[\,1 + (\alpha\, h)^{n}\,]^{(1/n-1)} \qquad [1]$$

where, ω = water content at a given pressure head, kg/kg; ω_o = water content of saturated paste, kg/kg; ω_{15} = water content at 1500 kPa, kg/kg; h = equilibrium air pressure, kPa and α (1/kPa) and n are curve shape parameters. Placing ω_o and ω_{15} equal to the measured values, we estimated α and n by using a non-linear least squares approximation (Marquardt 1963).

Prediction of Volumetric Water Contents

From the mass balance equation, the water contents of soil-coal mixture samples, at a given pressure, can be linearly interpolated as (Sharma et al. 1993):

$$\omega_m = (1 - c_f)\,\omega_s + c_f\,\omega_c \qquad [2]$$

where, ω_m = water content of mixture at a given h, kg/kg; ω_s = water content of soil, kg/kg; ω_c = water content of coal, kg/kg; and c_f = coal fraction by weight, kg/kg.

From the volume balance equation, the particle as well as the bulk density of a soil-coal mixture can be predicted by the following interpolation equation (Sharma et al 1993).

$$\rho_m = \rho_s\,\rho_c \,/\, ((1 - c_f)\,\rho_c + c_f\,\rho_s) \qquad [3]$$

where ρ_m = density of mixture, Mg/m^{-3}; ρ_s = density of soil, Mg/m^{-3}; and ρ_c = density of coal, Mg m^{-3}. From water retention parameters of Eq. [1] for component coal and soil samples, the volumetric water content vs. pressure head data for the soil-coal mixture samples were generated by using Eqs. [2] and [3].

RESULTS AND DISCUSSION

Physical Properties

Table 1 lists the mean values of particle size distribution, cations in the saturation extract, and the SAR of the component samples. The coal samples had more than 90% of their weight contributed by coarse fragments ranging in size from 0.10 to 2.0 mm. Both the mechanically ground samples of commercial coal and the naturally fragmented samples of degraded lignite show similar particle size distributions. Table 1 shows that the silty clay loam soil sample and the two coal samples had considerably higher proportion of Na^+ in comparison to the amounts of Ca^{++} and Mg^{++}. As a result, these three samples show very high SAR (> 20) compared to that of sandy loam and loam samples (SAR ≤ 2).

Table 1. Particle size distributions, cations in the saturation extract, and sodium adsorption ratios of component soil and coal samples used in the experiment.

	Component samples				
Properties	Sandy loam	Loam	Silty clay loam	Commercial lignite	Degraded lignite
Particle size range, mm	Particle size distribution, %				
1.0 - 2.0	< 1.0	< 1.0	< 1.0	52.2	46.7
0.5 - 1.0	< 1.0	1.3	< 1.0	21.7	23.7
0.25 - 0.5	< 1.0	4.3	< 1.0	8.4	10.2
0.10 - 0.25	38.6	18.3	< 1.0	9.3	11.2
0.05 - 0.10	28.2	13.4	10.4	4.8	5.0
0.002 - 0.05	23.9	36.3	58.7	3.6	3.1
< 0.002	9.1	25.8	28.9	0.0	0.0
	Cations in saturation extract, mmol L^{-1}				
Calcium	0.69	8.65	0.12	7.19	4.24
Magnesium	1.03	15.55	0.11	8.11	5.38
Sodium	2.37	9.87	15.73	93.82	78.84
Sodium adsorption ratio (SAR)	1.83	2.00	33.34	23.99	25.43

Densities

Table 2 lists the particle and bulk densities of the component soil and coal samples. The particle densities of the three soil samples are relatively higher than assumed particle density of 2.65 Mg m^{-3} for mineral soils. The particle densities of the two coal samples were < 2.0 Mg m^{-3}, and the bulk density bulk densities were < 0.8 Mg m^{-3}.

For the coal samples and the sandy loam and loam samples, the differences between saturated paste and oven-dry bulk densities were relatively small (Table 2). These differences are mainly due to differences in sample handling procedures which induced sample variability related to particle packing and confinement. For the silty clay loam sample, the mean bulk density of saturated paste was 0.61 Mg m^{-3} compared to the bulk density of 0.95 Mg m^{-3} for the oven-dry sample. This difference in bulk density, the high sodicity (SAR=33) and high saturation water content (1.285 kg/kg) are indicators of swelling potential of the silty clay loam sample which has abundance of smectite with Na-montmorrilonite minerals (Groenewold et al.1983, Merrill et al 1987).

Table 2. Densities, gravimetric water contents at saturation, at 1500 kPa, and at air dry conditions, water repellency indices, and soil water retention parameters for the component soil and coal samples.

	Component samples				
Properties	Sandy Loam	Loam	Silty Clay Loam	Commercial Lignite	Degraded Lignite
	Mg m^{-3}				
Particle density	2.70(9)[†]	2.81	2.79	1.76(7)	1.87(7)
Bulk density					
Saturated paste[‡]	1.39	1.03	0.61	0.62	0.75
Oven-dry samples	1.28	1.20	0.95	0.61	0.66(8)
Water contents	kg kg^{-1}				
Saturation	0.348	0.620	1.285	1.043	0.793
1500 kPa	0.037	0.115	0.251(7)	0.416	0.415
Air-dry	0.015	0.040	0.052	0.200	0.187
Water repellency index (WRI)	1.32(12)	0.99	86.30	227.8(11)	1.07(31)
van Genuchten parameters[§]					
α (kPa^{-1})	0.207(32)	0.422(26)	1.159(125)^{ns}	-	0.114(51)^{ns}
n	1.796(15)	1.505(7)	1.344(19)	-	1.836(25)

[†] Numbers in the parenthesis are coefficients of variation (%) calculated from the ratio of standard deviation to the mean of six sub-samples. All other means had CV's ≤ 5%.

[‡] Calculated by Eq.[1]. [§] The CV's (%) of the parameters are calculated from the ratio of standard error to the mean. ^{ns} Not significant by t-test at P=0.05 with df = 5.

Water Repellency

The commercial lignite and the silty clay loam samples were highly water repellent with WRI's of about 228 and 86, respectively (Table 2). The sandy loam, loam and the degraded lignite samples were not repellent to water with WRI's approximately equal to 1. Although the samples were not biochemically analyzed, the high water repellency of the commercial lignite sample is attributed to the presence of undecomposed lignin type organic polymers on its surface, on which, water drops with higher surface tension can not penetrate easily (Richardson and Wollenhaupt 1983). The low water repellency of the degraded lignite sample is probably due to oxidation of lignin by prolonged exposure on the old stockpile.

Water Content versus Coal Content

Figure 1 shows the water contents of the three soil samples mixed with various amounts of the two coal samples at different desorption pressures and for saturated paste. For non-sodic soil samples mixed with the degraded lignite (solid lines and symbols in Fig.1 for sandy loam and loam), the gravimetric water content of the mixtures increased linearly with increase in coal content. For the sodic silty clay loam mixture (up to 50%) with the degraded lignite, water content of saturated paste decreased proportionally with increase in coal content. For desorption pressures from 5 to 1500 kPa, the water contents did not show appreciable change.

For the three soils mixed with the commercial lignite from 0 to 50% by weight, the trend of relationships between water contents and coal contents (broken lines and symbols in Fig.1) were similar to mixtures with those of degraded lignite. However, at a given coal content, the water contents of commercial lignite mixed samples were consistently higher than those of degraded lignite mixed samples. The difference was more apparent at lower pressures and higher coal contents. This observation was not apparent (except at 50% coal content) for coal-mixed silty clay loam samples.

Unlike mixture samples with soil, the 100% samples of commercial lignite showed consistently lower water contents than those of degraded lignite at desorption pressures of 5 to 100 kPa (Fig.1). For sandy loam and loam samples mixed with the commercial lignite, the saturated water contents of the mixtures increased linearly with the coal content up to 100%. This was due to facilitation of wetting by the mechanical mixing involved in the preparation of the saturated paste. From these observations, it is suspected that during wetting before the desorption on the pressure plates, the high water repellency possibly prevented the commercial lignite samples from becoming completely wet. As such, the desorption water contents of commercial lignite samples specifically at lower pressure heads (5 to 100 kPa) were underestimated.

Water Retention Characteristics of Component Samples

Figure 2(a) shows the measured gravimetric water contents of saturated paste and at various equilibrium pressures at which the component samples were desorbed. Table 2 shows the parameters (α and n) of the fitted water retention curves shown as solid lines in Fig. 2(a). Figure 2(b) shows the corresponding measured (symbols) and fitted (solid lines) volumetric water content versus pressure head relationships of the five component samples. Compared to the three soil samples, coal samples showed a smaller range of water retention between 5 kPa and 1500 kPa water contents. At lower desorption pressures, the coal samples retained volume of water similar to that of loam sample; at higher desorption pressures, coal samples behaved like the sodic silty clay loam sample.

Measured vs. Predicted Water Contents of Soil-Coal Mixtures

Figures 3(a) and 3(b) show the comparisons of the predicted volumetric water contents of soil-coal mixtures with those measured in this experiment. For both the commercial and the degraded lignite mixed samples, the predicted volumetric water contents matched the measured values with acceptable accuracy. The predicted volumetric water contents were more accurate for sandy loam and loam samples mixed with both types of coal. As expected, the predictions showed more error for the sodic silty clay loam soil and for the soil samples mixed with the commercial lignite.

CONCLUSIONS

1. At all pressure heads, water contents of nonsodic, sandy loam and loam samples mixed with degraded lignite (low water repellency) were linearly proportional to the coal contents. The deviations from linearity increased with the presence of either water repellent coal or sodic clay material.

2. Given the soil water content versus pressure head relationships of component soil and coal samples, the water retention characteristics of mixture samples could be predicted by interpolations based on mass and volume balance relationships of soil-coal mixtures.

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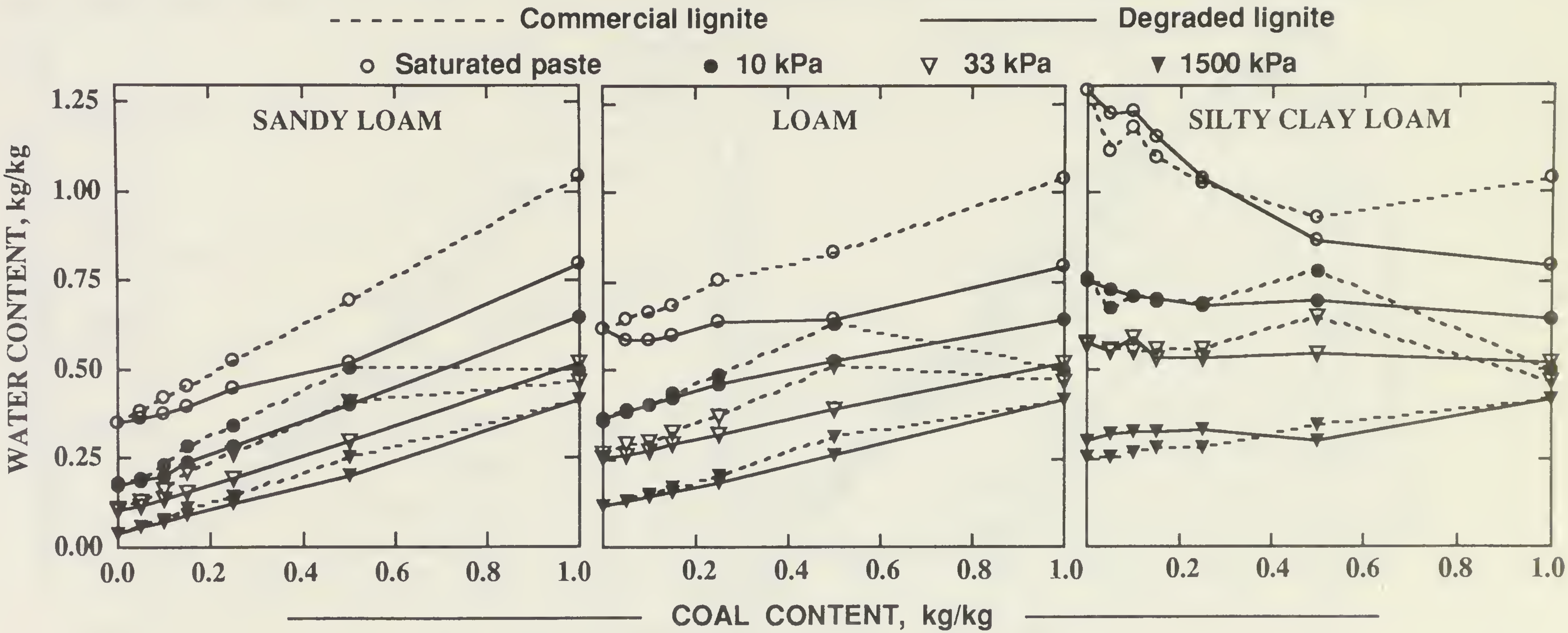

Fig. 1: Water content versus coal content relationships (by weight) of sandy loam, loam, and silty clay loam samples mixed with commercial and degraded lignite. For clarity, data for 5, 100, and 500 kPa are not shown.

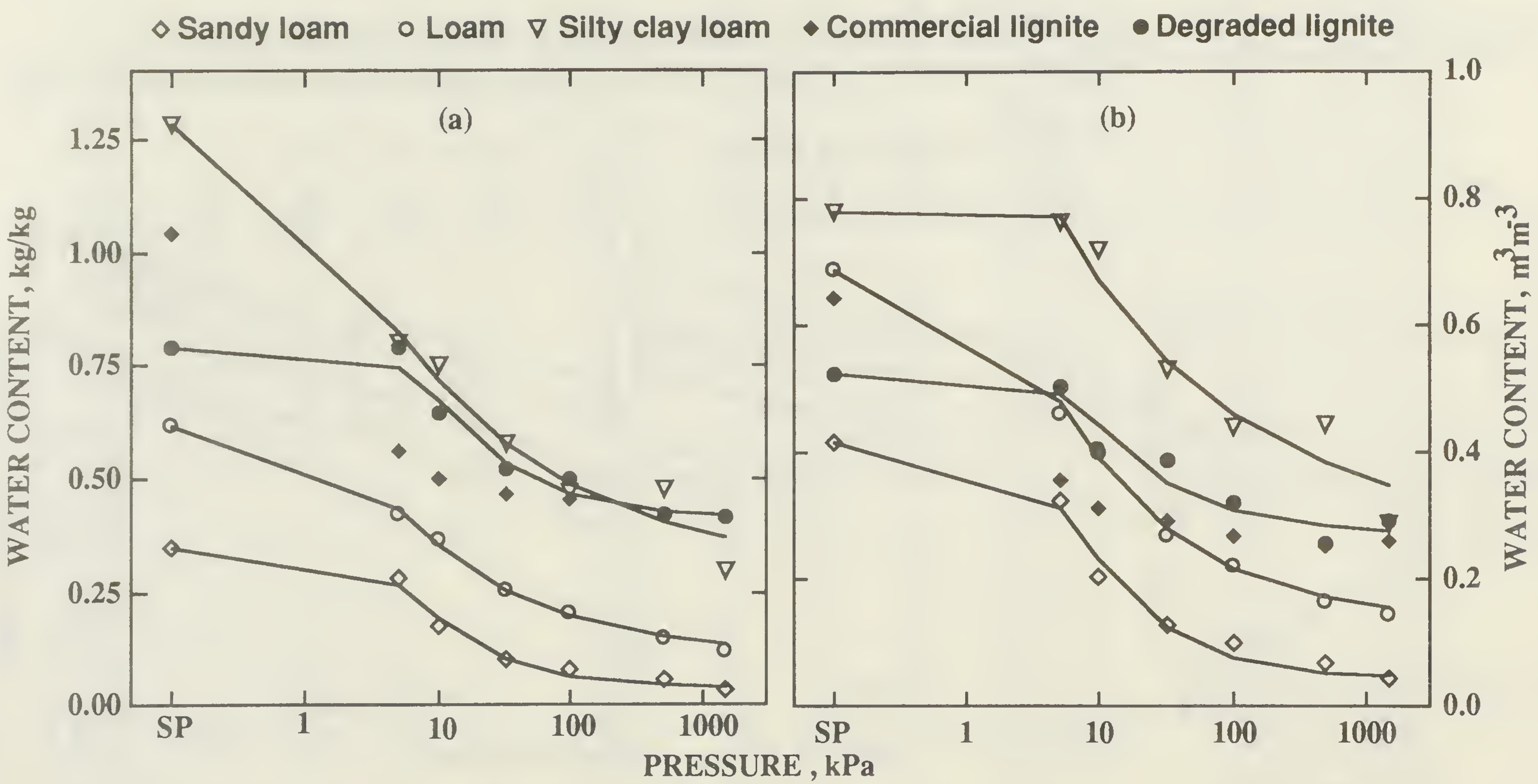

Fig. 2: Soil water content (a) by weight and (b) by volume as functions of desorption pressures for the five component samples. Values corresponding to 'SP' show the water contents of saturated paste. The symbols denote arithmatic mean of measured water contents determined (a) by oven-drying and (b) by multiplying with corresponding bulk densities of desorbed samples. For saturated paste, the theoretical bulk density was used. The solid lines represent (a) fitted curves by Eq. [1] and (b) calculated curves by multiplying the fitted values in (a) with the overall mean bulk densities of the component samples.

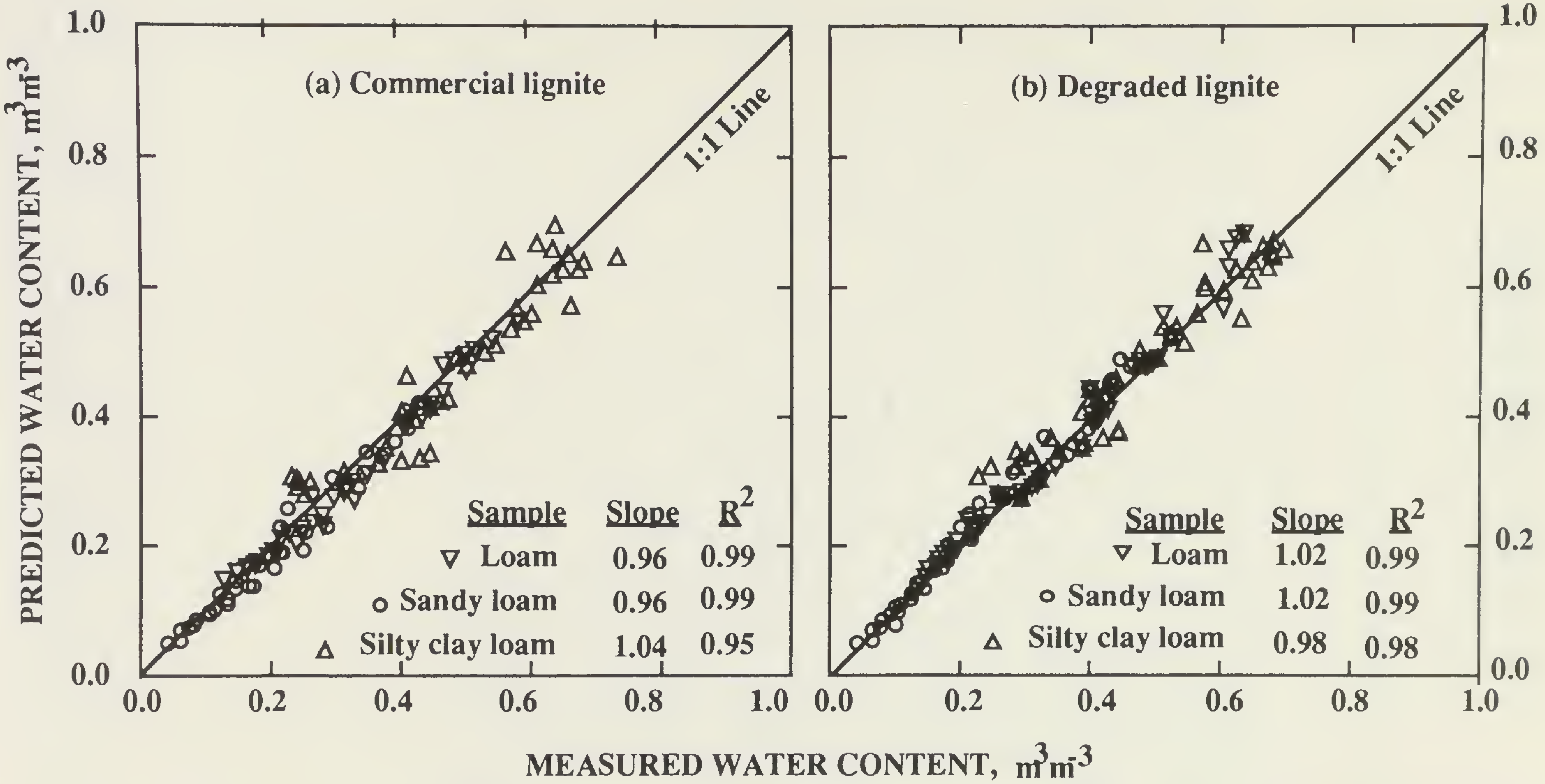

Fig. 3: Predicted versus measured water contents of soil samples mixed with (a) commmercial lignite and (b) degraded lignite at desorption pressures ranging from saturation to 1500 kPa. The water contents were predicted using Eqs. [1], [2], and [3].

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SAMPLE SPACING REQUIREMENTS FOR TOPDRESSING REMOVAL AT NAVAJO MINE, NEW MEXICO

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ABSTRACT

Navajo Mine is located in northwest New Mexico. Prior to mining, the depth and amount of suitable topdressing must be estimated from intensive surveys for the areas to be disturbed. Approximately 175 acres a year are surveyed by locating test pits on a grid spacing with 200' centers. This is approximately one test pit per acre. Thickness of suitable topdressing is determined at each test pit to a depth of 60" or to bedrock, whichever is more shallow. Slightly less than 425 acres were evaluated in the Lowe pit area of the mine and 522 test pits were sampled in this area from 1989 to 1992. It has been observed that of the 10 different soil map units in the Lowe area, some units seem to have been "oversampled" and some "undersampled". The objective of this program was to determine if sample spacing requirements were different for dissimilar soil map units. The map units ranged in size from 3.2 acres to 243.4 acres. A mean depth and standard deviation of suitable topdressing was determined for each map unit. The required number of test pits and their spacing was calculated for each of the 10 map units. Test pit spacing ranged from 40' to 740' with four of the map units requiring a spacing less intense than 200' and six of the units requiring a spacing more intense than 200'. Spacing and location of future test pits should be based on the composition of the soil map units at Navajo Mine. The application of a uniform grid to map units that are non uniform may not accurately predict the mean depth or amount of suitable topdressing.

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INTRODUCTION

Navajo Mine is located in the San Juan Basin of northwest New Mexico. A reconnaissance survey of the soil resources at Navajo Mine was completed in 1989. A total of 26 map units and 31 soil series were identified on the 11,733 acre survey area. This survey indicated only one third of the undisturbed area would provide suitable topdressing material and that the remaining two thirds consisted of either Badlands or salt affected soils that would not provide suitable sources of topdressing. Several of the map units were relatively homogenous consociations and some of the map units were complexes that consisted of two or more components. The complexes are relatively heterogenous with regard to their topdressing suitability.

Each year soils suitable as topdressing are removed from approximately 175 acres in preparation for mining. The topdressing material is later applied to regraded spoil as part of the reclamation program. The location and amount of suitable topdressing is determined by pre-strip surveys. These surveys are required for all areas to be disturbed and are completed by sampling backhoe test pits located on a 200' center grid (one test pit per acre). Therefore, the 200' grid is uniformly applied to every map unit. It has been observed that the 200' grid seems to "oversample" some of the homogenous map units and "undersample" some of the heterogenous units. Also, sampling the Badlands and some of the salt affected soils does not seem to be necessary.

The hypothesis was that homogenous soil map units require less intense sampling than heterogenous units. Therefore, the objective of this program was to determine if the sampling requirements would be different for dissimilar map units. Sampling was defined as the number of test pits, excavated to five feet, required to estimate the mean depth of suitable topdressing in a map unit at Navajo Mine.

METHODS

The area selected for this program is known at the mine as Lowe pit mining area. A total of 10 map units were identified in the area in 1989 and they represent a wide range of soil types found at Navajo Mine. Some soils are deep, representing some of the most suitable sources of topdressing at the mine, and others are moderately deep, shallow, or very shallow, representing different amounts of suitable topdressing. Also included in the study area are Badlands and salt affected soils representing unsuitable sources of topdressing.

Test pits were located on a 200' center grid for the entire study area, and they were excavated at various times from 1989 through 1992. In some map units test pits were excavated more intensely than on the 200' grid. The frequency was a judgement by the soil scientist with regard to the homogeneity of the unit and its potential to yield suitable topdressing. Depth of suitable topdressing was estimated at each test pit location to a depth of five feet or to bedrock, whichever was more shallow. Suitability was verified by chemical and physical analyses of soil samples collected from the test pits. Analyses were completed by Inter-Mountain Laboratories, Farmington, NM. The suitability guidelines (Table 1) were those approved in the Navajo Mine permit.

Each test pit location was grouped into its respective soil map unit. A sample mean and sample standard deviation of suitable topdressing depth was then established for each map unit from the test pit data. The number of samples required to adequately predict the mean topdressing depth for a map unit could be determined from the standard deviation established for the respective map unit. The formula used to predict sample size follows:

[1] $N = (S(2T)/w)^2$

Where:

N = sample size
S = standard deviation
T = t-value at 95% confidence
W = width of confidence interval

Initially N was arbitrarily estimated to be a value of 60 and therefore a t-value of 2.0 was used in the formula. Once an approximate N was established, a new t-value was used in the formula. This process was repeated until the N value did not change with a new t-value. The width of the confidence interval was based on what was considered a reasonable level of accuracy for estimating topdressing thickness from soils of various depths. It was important to have higher accuracy for soils with thin depths of topdressing, whereas soils with thicker topdressing did not require as high a degree of accuracy. Therefore, a width of 8" (±4" about the mean) was used for soils having a mean depth of suitable topdressing of less than 36". A width of 12" (± 6" about the mean) was used for soils having a mean depth of suitable topdressing of 36" and greater. After the sample size (N) was determined for each map unit, a sample spacing was calculated. The formula used to predict sample spacing follows:

[2] $S = (Amu \times 43560/N)^{1/2}$

Where:

S = sample spacing (ft)
Amu = acres of map unit
N = sample size

RESULTS AND DISCUSSION

A total of 522 test pits were evaluated for topdressing depth suitability in a total area of 423.5 acres. There were 10 map units (Table 2) ranging in size from 3.2 acres to 243.4 acres. The mean depth of suitable topdressing (Table 2)

Table 1. OSMRE Topdressing Suitability Guidelines for Navajo Mine.

Characteristic	Suitable	Unsuitable
pH (saturated paste)	5.5 - 8.8	< 5.5
Electrical conductivity (dSm^{-1})	0 - 12	> 8.8
Sodium adsorption ratio (based upon fine-earth texture)		
sandy loam & coarser	0 - 18	> 18
loams & clay loams	0 - 16	> 16
texture > 40% clay	0 - 14	> 14
Fine-earth texture	0 - 45% clay	> 45% clay
$CaCO^3$ (%)	0 - 15	> 15
Rock fragments, based upon fragment size (%)		
0.2 - 25 cm (0.8 - 10 in)	0 - 35, non-skeletal	> 35, skeletal
> 25 cm (> 10 in)		> 0
Dry consistence	loose, soft, hard, slightly hard	very hard, extremely hard
Bedrock		lithic & paralithic (R & Cr horizons)
Boron	≤ 10 ppm	> 10 ppm
Total Selenium[1]	≤ 0.8 ppm	> 0.8 ppm
Soluble Selenium[1]	≤ 0.15 ppm	> 0.15 ppm

[1] Revisions to these standards are pending.

Table 2. Mean depth of topdressing and sample spacing requirements for 10 map units in the Lowe pit mining area, Navajo Mine, New Mexico.

Map unit	Area, Acres	Test[1] pits	Mean topdressing depth, inches	Standard deviation inches	N[2] Value	Sample[3] spacing
Badland	18.8	24	1.3	3.0	5	405
Blancot	12.5	16	60.0	0.0	1	740
Jocity-Gilco	23.3	24	48.6	19.8	44	158
Jocity very hard	8.5	6	59.2	2.0	1	610
Mayqueen-Shiprock	35.5	42	48.8	21.6	52	172
Natrargids	243.4	310	12.3	20.6	105	318
Natrargids overblown	42.9	57	27.8	25.6	163	107
Razito	31.7	35	52.5	18.1	37	193
Razito very hard	3.2	4	6.7	11.6	17	90
Shiprock-Blancot	3.7	4	45.0	30.0	98	40
TOTAL	423.5	522			523	

[1] Number of test pits located in the respective map units. An attempt was made to have one per acre.

[2] N value is predicted using the formula $N = (S(2T)/W)^2$
Where:
N = sample size
S = standard deviation
T = t-value at 95% confidence
W = width of confidence interval

[3] Sample spacing is the mean distance of a sample grid for the location of test pits.

ranged from 1.3" to 60" for the various map units. The required sample size and sample spacing are given in Table 2. Sample spacing intensity ranged from 40' to 740' and varied for the different map units as was expected. Only a few of the sample spacing requirements for the map units were near a 200' spacing.

The Badland map unit was estimated to have a mean depth of suitable topdressing of 1.3" and required a sample spacing of 405' to predict this depth within ± 4" with a 95% confidence. The Badland unit is the easiest map unit to identify at the mine and sampling for suitable topdressing at any intensity is considered to be unnecessary. Certainly a map unit having slightly more than one inch as the mean depth of topdressing should not be included in the topdressing removal program.

Two of the map units, Blancot and Jocity very hard phase, had mean topdressing depths of near 60" and required a sample spacing of 740' and 610', respectively. These map units are important to the mine because they are deep sources of topdressing and relatively homogenous. This study suggests that they require a much less intense spacing than a 200' grid to predict the mean depth and amount of topdressing.

Another map unit that required a sample spacing less intense than 200' was the Natrargids. These are salt affected soils and generally are not sources of suitable topdressing. In this area they comprised 243.4 acres or 57% of the study area compared to 32% of the undisturbed portion of the entire mine lease. The topdressing available in this map unit was typically located near the borders of the map unit delineations. The map unit was found to require a sample spacing of 318' to estimate the mean topdressing depth. This unit would be best sampled, in this area and other parts of the mine, by more intensely sampling near the borders of the delineations and sampling less intensely within the interior of the delineations. These types of decisions could be made by a qualified soil scientist.

Three map units were found to have sample spacing intensities slightly less than 200'. The Jocity-Gilco, Mayqueen-Shiprock, and Razito units had respective sample spacings of 158', 172', and 193' and respective suitable topdressing depths of 30", 51", and 54". These units are important sources of topdressing to Navajo Mine and collectively represent about 7.5% of the undisturbed portion of the entire mine lease. In this study they collectively represented about 22% of the area. Topdressing depth in these map units would be more accurately predicted using a sample spacing less than the standard 200' spacing.

The Natrargids overblown phase map unit is composed of salt affected soils that have an eolian sand deposit on the surface. The depth of the sand was variable as indicated by the standard deviation (Table 2) which was nearly equal to the mean depth of topdressing. Based on 57 test pit sites, a spacing of 107' was needed to predict the mean depth and amount of topdressing for this map unit. This spacing intensity may be representative for this map unit in other parts of the mine lease as well. It is clear that for this map unit a 200' sample spacing was not adequate to predict the mean depth within ±4" with a 95% confidence.

The two remaining map units, Shiprock-Blancot and Razito very hard phase, were found to require sample spacings of 40' and 90', respectively. These same units had respective mean depths of suitable topdressing that were 45" and 6.7". The acreage and number of test pits for these two map units were small in this study. Their collective acreage was 1.6% of the study area which is representative of their extent on the entire mine lease, about 1%. Both the Shiprock-Blancot and Razito very hard phase units are important sources of topdressing. Therefore, it is important that these map units are properly sampled. The number of test pits used in this study was too small to adequately predict sample spacing requirements for these map units and will require further study.

CONCLUSIONS

Presently, pre-mine areas at Navajo Mine are uniformly surveyed for suitable topdressing using a 200' center grid. The areas surveyed at Navajo Mine are composed of 28 different soil map units that are variable in their homogeneity and subsequently the amount of suitable topdressing available is also variable. A uniform sampling grid applied to all map units is not appropriate for sampling these units. Some map units are homogenous and the topdressing amount is easily predicted and therefore require a low intensity of sampling. Other map units are heterogenous and the topdressing amount can only be predicted with a high intensity of sampling, in some cases more frequently than on a 200' center grid. This study supports the original hypothesis that the various map units will require different sampling intensities.

Plans for future sampling of topdressing at Navajo Mine should be developed with consideration for the existing map units. The intensity of sampling should be decided with regard to the homogeneity of an unit and its potential to yield suitable topdressing.

SAMPLE RELIABILITY OF REPLACED SURFACE-MINED COAL SPOILS

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ABSTRACT

Small spoil samples are often assumed to characterize vastly larger quantities of spoils in reclaimed landscapes. This practice is not always justified. Replaced spoil samples from 24 sites at the Antelope Coal Mine were sampled between 1987-1991 and analyzed for EC, SAR, acid-base potential, and hot-water extractable selenium and boron concentrations. In 1992, spoils from the same sites were resampled and analyzed. For the three most variable factors (acid-base potential, selenium, and boron), correlations ranged from 0.01 to 0.40, and statistically significant differences ($p < 0.10$) between the two sampling periods were lacking. For these three parameters, spoil samples did not seem to represent a volume larger than the sample itself. We question whether small spoil samples adequately characterize variable spoil parameters at sample locations, and suggest that areas of unsuitable spoils should not be inferred from them. The least variable parameters, EC and SAR, were also the best correlated.

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INTRODUCTION

Spoil sampling is relied upon to characterize spoil quality characteristics of reclaimed landscapes. Above or below certain levels, various spoil characteristics may limit reclamation success. At the Antelope Coal Mine, samples from regraded spoil surfaces are taken on a 400-foot grid, with samples composited at each site for 0-2' and 2-4' depth intervals. The implicit assumption of such sampling is that small spoil samples characterize vastly larger quantities of surface spoils. This study investigated whether spoil samples reliably characterize even the immediate proximity of sample locations for five common spoil parameters.

STUDY AREA

The Antelope Coal Mine is located about 65 miles south of Gillette, WY, along the eastern edge of the Powder River Basin. Coal and overburden consist of sedimentary Fort Union Formation materials. The interbedded overburden deposits have an average thickness of 84 feet, consisting of poorly consolidated clays, shales, siltstones, and sandstones.

At the Antelope Coal Mine, overburden movement by dragline results in dual mixing: first from cutting, and second from dumping. During the excavation process, the dragline bucket is drawn up the overburden face, cutting through several sedimentary layers, which are not necessarily homogeneous with respect to spoil characteristics. When the bucket is filled by this process, it revolves via the boom over the spoil dump and discharges its contents. Spoil ridges are formed at the angle of repose, and the contents of subsequent buckets tumble down from ridge top along the slope.

Regrading of dragline spoils involves smoothing the surface by pushing spoil ridges into adjacent valleys. Mixing occurs as spoils are dozed and cascade down angle-of-repose slopes, filling valleys. Regrading brings the surface to the approved post-mining topography.

OBJECTIVES

Between 1987 and 1991, 24 locations in approximately 85 acres of regraded spoils at the Antelope Coal Mine in the southern Powder River Basin, WY, were individually sampled as each was brought to its final reclamation configuration. Spoils at the same locations were resampled in 1992.

Sample/resample reliability was evaluated for five common spoil parameters.

METHODS

Approximately two kilograms of spoils were hand-augered from 24 previously sampled sites, which were relocated by their survey coordinates. The accuracy of re-establishing sample locations was within one foot. Samples from the 0-2' and 2'-4' depth intervals of regraded spoils were collected, placed in sealed plastic bags, identified by site number, and transported to Inter-Mountain Laboratories Inc., in Sheridan, WY. Sample sizes were 24 for the 0-2' depth interval and 20 for the 2-4' depth interval due to the inability to auger extremely rocky spoils.

Spoils were analyzed for the following parameters: electrical conductivity (EC, a measure of salinity), sodium adsorption ratio (SAR, a ratio of the abundance of sodium relative to calcium and magnesium cations), acid/base potential (ABP), and hot-water extractable selenium (Se) and boron (B) concentrations. These spoil parameters were selected because the baseline geology study identified potentially unsuitable materials based on them.

Laboratory references for spoil analysis are as follows: EC - USDA 1954, pp. 89-90; SAR - USDA 1954, pp. 26 and 84; ABP - Smith and others 1974 and USDA 1954 p. 105, and calculated Acid-Base Potential = Neutralization Potential - Acid Potential; water soluble Se - ASA 1965, with analysis by AA or ICP; B - ASA 1965, with analysis by AA. The detection limits for Se and B were .02 and 0.1 ppm respectively, and values of 0.015 and 0.007 ppm, respectively, were assigned to samples with concentrations below the detection limits.

Through-time comparisons were evaluated using paired t-tests and Pearson product-moment correlations. When more than one value per location from previous sampling was available, the mean of previous values was used.

QUALITY CONTROL

Through-time comparisons are partially dependent upon the precision of analytical procedures. Precision refers to the repeatability of measurements. During the course of sampling, Inter-Mountain Laboratories provided analysis of 13 laboratory splits. The results, summarized in Table 1, show that laboratory precision is good for all factors except B. None of the paired means differed significantly at $p < 0.10$.

Table 1. Summarized results of 13 laboratory splits of spoils for EC, SAR, ABP, B, and Se.

PARAMETER	MEAN 1	MEAN 2	CORRELATION
EC (mmhos/cm)	4.77	4.89	0.97
SAR	5.56	5.50	0.98
ABP (t/1000t)	2.71	2.60	0.99
B (ppm)	0.19	0.17	0.61
Se (ppm)	0.17	0.17	0.97

Unknown to the laboratory, we supplied a field split of one spoil increment sample for analysis. The contents of the auger tube were split into two subsamples. Thus, the subsamples were not comprised of exactly the same material, but of materials from the same sample hole and same depth increment. While a single pair of samples cannot be compared statistically, the values for ABP and Se appear to differ significantly (Table 2). Given the generally precise laboratory results for splits of homogeneous materials (Table 1), we think that the differences shown in Table 2 are a consequence of extremely heterogeneous regraded spoils.

Table 2. Spoil analysis results for a single blind split sample of the 0-2' depth interval.

PARAMETER	SAMPLE A	SAMPLE B	%DIFFERENCE
pH	7.2	7.7	7
EC (mmhos/cm)	9.7	7.7	21
SAR	7.9	7.4	6
ABP (t/1000t)	0.25	0.15	40
B (ppm)	0.12	0.14	17
Se (ppm)	0.25	0.15	40

RESULTS

Comparisons and contrasts of initial and 1992 sampling and analyses are summarized in Table 3. Comparing the means from previous and 1992 sampling suggest some differences between 1987-1991 and 1992 sampling, but only four differences were statistically significant (Table 3). Significance refers to whether the means differed significantly at $p < 0.10$ based on paired t-tests.

The calculation for paired t-tests depends on the difference between means (numerator) and the standard error of the paired differences (denominator). Large differences between means and small standard errors contribute to significance. In the case of ECs for the 0-2' depth interval, the difference between means for previous and 1992 samples was small (0.2 mmhos/cm), hence the numerator in the t-calculation was small and the difference not significant.

Selenium concentrations in the 0-2' depth interval (Table 3) provide a very different example. In this case, the difference between means (0.07 ppm) is relatively large, but the data comprising both means are highly variable (indicated by coefficients of variation [CV] of 80% and 123%, calculated from Table 3), and the differences between paired values are large (indicated by a very low correlation of .09). Hence, while the difference between means (numerator) is large, the standard error of the difference (denominator) is very large, and a significant difference cannot be established.

Standard deviations (Table 3) provide an estimate of the variance associated with each parameter. This topic is later addressed in Table 5 using CVs. ECs and SARs for spoils at the mine are less variable than ABPs and Se and B concentrations. The correlations between earlier and 1992 samples are higher for EC and SAR than for the more variable parameters.

Correlations are very pertinent in assessing resample reliability because they reveal the strength of relationships between previous and resample values. While high correlations do not indicate causality, low correlations do indicate a lack of relationship. Perhaps the most interesting finding of this study was the lack of relationship between sample/resample analyses for ABP, Se, and B.

Differences between paired samples from the same location are the primary focus of this investigation. The average

Table 3. Comparisons of previous (1987-1991) and 1992 spoil analyses at the same locations. (n = 24 for the 0-2' depth interval and n = 20 for the 2-4' depth interval.)

FACTOR	DEPTH	MEAN PREV.	S. D.*	MEAN 1992	S. D.	CORR-ELATION	SIGNIF-ICANCE
EC	0-2'	4.8	1.5	5.0	1.5	.62	>0.10
(mmhos/cm)	2'-4'	4.4	1.6	5.3	1.4	.72	0.002
SAR	0-2'	5.3	2.0	4.0	1.7	.56	<0.000
	2'-4'	5.2	2.1	4.4	1.5	.76	0.02
ABP	0-2'	3.0	7.1	5.7	11.6	.01	>0.10
(t/1000t)	2'-4'	3.6	11.0	2.6	10.7	.40	>0.10
Se	0-2'	.10	.08	.17	.21	.09	>0.10
(ppm)	2'-4'	.09	.08	.18	.14	.40	.01
B	0-2'	.24	.19	.18	.09	.04	>0.10
(ppm)	2'-4'	.23	.27	.17	.08	.23	>0.10

*S.D. Standard deviation.

differences between paired spoil parameter values are presented in Table 4 and compared to sample means for each sample period. Differences in Table 4 were computed for each pair of samples from the same location) regardless whether that difference was higher or lower (i.e., the average of absolute values of differences between paired values).

Table 4. Average differences between paired spoil samples compared to means of previous (1987-1991) and 1992 spoil analyses.

FACTOR	0-2' DEPTH			2-4' DEPTH		
	PREVIOUS	1992	DIFF.	PREVIOUS	1992	DIFF.
	MEANS					
EC*	4.82	5.00	1.05	4.38	5.33	1.12
SAR	5.32	4.00	1.60	5.18	4.37	1.14
ABP*	3.00	5.72	9.91	3.60	2.64	9.30
Se*	.10	.17	.14	.09	.18	.11
B*	0.24	.18	.15	.23	.17	.15

*EC in mmhos/cm; ABP in t/1000t; B and Se in ppm.

DISCUSSION

ECs and SARs are the best correlated and least variable parameters at the Antelope Coal Mine (Table 3). The average value for both parameters ranges from 4 to 5.3, and the average differences range from 1.05 to 1.6 (Table 4). Sample reliability appears to be acceptable for these parameters, with the caveat that ECs and SARs were not as variable as other parameters.

The correlations for EC (Table 3) are the best of any parameters investigated. The average difference for paired ECs is about 20% of the means (from Table 4). Given the rather high correlations and significant difference, we conclude that EC has increased in the 2-4' depth interval over several years. The difference has little practical significance because all EC means denote borderline saline conditions.

Differences in SARs for both depth intervals are statistically significant, and the correlations are relatively good (Table 3). The average difference between paired samples is about 28% of the means (Table 4). We conclude that SARs in the upper four feet of regraded spoils have decreased over several years. Mean SARs are below the level at which sodium usually causes reclamation problems.

The ABP resample correlation for the 2-4' depth interval was poor, and there was no correlation for the 0-2' depth interval (Table 3). The average difference in ABP between paired samples was large (Table 4). Given good laboratory precision for ABP (Table 1), we conclude that ABP samples characterize only the spoils analyzed, and inferences to proximate spoils are not justified at the Antelope Coal Mine.

Selenium concentrations were highly variable and poorly correlated (Table 3). The average difference in Se concentration from the same locations was 58% of the mean for the 0-2' depth interval and 35% of the mean for the 2-4' depth interval (Table 4). We cautiously conclude that extractable Se concentrations may have increased in the 2-4' depth interval. However, the poor correlations and large differences between paired samples, in conjunction with good laboratory precision (Table 1) and a large difference for proximate samples (Table 2), suggest that Se concentrations in spoil samples at the Antelope Coal Mine characterize only the samples themselves, and often do not represent spoils in general or even spoils near sample locations.

Boron concentrations were poorly correlated in the 2-4' depth interval, with no correlation for the 0-2' interval (Table 3). Average differences in paired values were about as large as the means (Table 4). Laboratory precision was low (Table 1). We conclude that B concentrations have not changed over time, and further that hot-water extractable B concentrations from spoil samples reliably characterize neither the samples nor proximate spoils.

Heterogeneity in replaced spoils is a consequence of overburden/spoil moving procedures and the inherent variability of overburden with respect to each spoil parameter. Extensive mixing is a consequence of the mining/ backfilling/regrading process. This does tend to blend spoils over large areas, but can also result in high variability in spoil characteristics over small areas.

To determine whether the same spoil parameters were most variable in both overburden and regraded spoils, means and CVs were computed for 100 overburden core sample segments (1987-1990) from 10 holes. Core segment lengths were determined by lithology or systematically. Means and CVs for overburden and spoils are presented in Table 5. Spoil parameter means and CVs were summarized from Table 3. Comparing the CVs for the same parameters in Table 5 reveal that EC and SAR were again less variable than the other three parameters, although the EC of overburden was more variable than anticipated based on surface spoil data.

Table 5. Overburden and spoil characteristics compared.

FACTOR*	OVERBURDEN MEAN	OVERBURDEN C.V.**	SPOILS MEAN	SPOILS C.V.
EC	3.2	63%	4.9	31%
SAR	6.5	39%	4.7	38%
ABP	11.8	31.7***	7.2	10.1***
Se	.09	93%	.14	90%
B	.36	130%	.21	73%

*EC in mmhos/cm; ABP in t/1000t; B and Se in ppm.
** Coefficient of Variation, the standard deviation expressed as a percentage of the mean.
***Standard deviation. The coefficient of variation for ABP is misleading because the mean incorporates negative values.

At the Antelope Coal Mine, the spoil parameters with the highest variance are the same factors with low resample reliability. ABP, Se and B were more variable, less well correlated, and had larger average differences among samples from the same location than ECs and SARs (Tables 3, 4, and

5). For the three most variable parameters, small spoil samples do not seem to represent a volume larger than the sample itself. The least variable parameters, ECs and SARs, were also the best correlated.

CONCLUSIONS

The sample/resample correlations for ABP, Se, and B are so low (Table 3), and the average differences for samples from the same locations so large relative to the means (Table 4), that we question their value for characterizing spoils at sample locations, much less inferring areas of unsuitable spoils. For these three parameters, statistically adequate sampling may serve to characterize the spoils collectively (i.e., determining average values), but does not reliably identify problem areas. Certainly any site-specific characterizations of replaced spoils with respect to ABP, Se, and B at the Antelope Coal Mine should be considered highly suspect.

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VARIABILITY OF CROP YIELDS ON RECLAIMED PRIME FARMLANDS

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ABSTRACT

Corn, soybean, and wheat yields were measured on several reclaimed mine sites using a plot combine. In some cases, whole field data were obtained, and in a few cases, hand-harvested yields of corn were determined. At two locations, corn yields were measured on non-mined prime farmland.

It was observed that even the method of harvesting may make significant differences in the yield reported for a given field. In general, yield variation both within and between strips harvested with the plot combine were similar. Strip harvests were good estimators of whole field measurements. Hand harvests were more variable, largely attributed to small sample sizes. Errors in hand harvests may change as much as 10 bu/a if an ear is missed or added to the sample. Variations in corn yields for the three methods used to disturb the soils were similar, but yields from truck-replaced soils appeared to be larger than from soils disturbed by either scrapers or dozers.

Variations in non-mined prime farmland soils were similar to those observed for reclaimed soils. Variations for soybean yields were slightly greater than that observed for corn. Wheat yields varied to about the same degree as corn.

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INTRODUCTION

Requirements for Phase III bond release for prime farmland requires proof of return of crop productivity to its original level. This requires measurement of grain yields, and in many states corn must be grown at least one year. Each state has developed regulations which involve methods for making such determinations. It is likely that differences occur between these agencies, although a survey was not conducted for this paper.

In Kentucky, variations in crop yields have been observed in an effort to develop a productivity index based on soil properties. For this project,[2] yield data were collected for corn, wheat, and soybeans, with the majority of effort directed toward corn.

Variations in yield within a field, between fields, and for the same field over time may be attributed to several factors. It may be difficult, if not impossible, to determine which of these factors are most important because many are interactive. Crops, especially corn, are sensitive to variations in fertility, such as N, P, and K; soil depth; soil bulk density; and even the variety may cause differences in production for most of the above parameters. Superimposed on the soil properties are variations due to climate, and there is the potential for interactions between climate and the crop variety.

The objective of this research was to: 1) determine the level of variations in crop yield occurring in reclaimed prime farmland, and 2) determine differences between three methods of harvesting corn on the reported yield component.

METHODS

Crop yields were determined for the most part with a Massey-Ferguson Model MF-8 research plot combine. This machine is equipped with weighing and moisture sensors that store the data in a computer. Heads are available to measure corn, wheat, and soybean yields; but the majority of the data reported here is for corn. All yields are in terms of standard moisture, but were not corrected for test weight since this parameter was not selected when the combine was purchased.

Yields were measured from strips across the various fields which in general were 50 feet apart. This procedure results in harvesting about 10% of each field. Within each strip, yields were integrated over a 50- to 75-foot interval depending on the crop, driving conditions, and, to a degree, the kind of crop and relative magnitude of the yield. Attempts were made to drive at a constant speed for the entire field.

In general, hand-harvested yields for corn were randomly chosen to represent the entire permit area. In each case, 15 feet of row was harvested, the shucks removed, weights and moistures determined, and yields reported on a grain basis at 15.5% moisture, as was also the case for the strips taken by the combine. In some cases, comparison in yields will be reported for the above two methods as well as that for the entire field.

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[2] Funded in part by the Office of Surface Mining Reclamation and Enforcement.

Yields were taken from fields in Kentucky and Indiana in which the soil had been replaced by either scraper pans or end-dump trucks. Notes as to the original soil series(s) that had been disturbed were made at each location. Soil samples, with depth, have been taken from most of these fields, but data will not be reported here. Site locations, restoration methods, and the dominate soil that was disturbed at each location are given in Table 1. The field numbers in this table may serve as a reference in subsequent tables.

Table 1. Site locations, restoration methods, and soils disturbed.

Field No.	Method	Location County/State	Dominate Soil Series and Classification[3] Prior to being Disturbed.
1	Scraper	Hancock Co. Ky	Belknap coarse-silty mixed Aeric Fluvaqualfs
2	Scraper	Daviess Co. Ky	Grenada fine-silty mixed Glossic Fragiudalfs
3	Dozer	Ohio Co. Ky	Weinbach fine-silty mixed Aeric Fragiudalfs
4	Scraper	Butler Co. Ky	Zanesville fine-silty mixed Typic Fragiudalfs
5	Scraper	Butler Co. Ky	Zanesville fine-silty mixed Typic Fragiudalfs
6	Scraper	Muhlenberg Co. Ky	Karnak fine, mont. Vertic Haplaquepts
7	Truck	Hopkins Co. Ky	Belknap coarse-silty mixed Aeric Fluvaqualfs
8	Non mined	Hopkins Co. Ky	Karnak fine, mont. Vertic Haplaquepts
9	Non mined	Ohio Co. Ky	Karnak fine, mont. Vertic Haplaquepts
10	Scraper	Ohio Co. Ky	Sadler fine-silty mixed Glossic Fragiudalfs
11	Dozer	Muhlenberg Co. Ky	Newark fine-silty mixed Aeric Fluvaqualfs
12	Truck	Ohio Co. Ky	Stendal fine-silty mixed Aeric Fluvaqualfs
13	Scraper	Muhlenberg Co. Ky	Zanesville fine-silty mixed Typic Fragiudalfs
14	Scraper	Muhlenberg Co. Ky.	Waverly coarse-silty mixed Typic Fluvaqualfs
15	Scraper	Muhlenberg Co. Ky.	Waverly coarse-silty mixed Typic Fluvaqualfs
16	Scraper	Ohio Co. Ky	Sadler fine-silty mixed Glossic Fragiudalfs
17	Truck	Ohio Co. Ky	Stendal fine-silty mixed Aeric Fluvaqualfs
18	Truck	Ohio Co. Ky	Bonnie fine-silty mixed Typic Fluvaqualfs
19	Truck	Ohio Co. Ky	Stendal fine-silty mixed Aeric Fluvaqualfs
20	Truck	Ohio Co. Ky	Weinbach fine-silty mixed Aeric Fragiudalfs
21	Scraper	Hopkins Co. Ky	Zanesville fine-silty mixed Typic Fragiudalfs
22	Scraper	Hopkins Co. Ky	Belknap coarse-silty mixed Aeric Fluvaqualfs
23	Truck	Warrick Co. In	Unknown (restored soil similar to Sadler)
24	Truck	Warrick Co. In	Unknown (restored soil similar to Belknap)

[3] All soils are in the mesic temperature region except Loring and Grenada.

RESULTS AND DISCUSSIONS

Corn

Data presented in Table 2 are for hand harvests taken from six fields in Kentucky. The first three fields had a mean yield of 160 bu/a, field 4 was 154 bu/a and the last two fields yielded near 130 bu/a. Yield variations occurred in all cases and ranged from 54 to 107 bu/a between individual sampling points. The overall average yield in this study did not seem to have an effect on the range in this variation.

Table 2. Corn yield variations observed in six fields determined by hand harvesting.

Sample	Field No.					
No.	1	2	3	4	5	6
	bu/a					
1	144	122	155	108	143	88
2	151	160	166	143	177	87
3	145	145	160	211	152	137
4	156	209	171	107	148	114
5	122	139	152	130	121	105
6	153	190	148	172	119	127
7	154	145	139	128	143	174
8	154	184	142	176	132	160
9	160	177	176	162	140	80
10	157	145	158	152	106	121
11	124	131	157	189	112	131
12	175	170	151	161	128	131
13	229	142	182	173	--	148
14	172	141	155	163	--	125
15	193	166	193	209	--	184
16	172	216	--	123	--	109
17	--	--	--	121	--	179
18	--	--	--	129	--	148
Mean	160	161	160	153	134	130
Max.*	107	94	54	103	65	104

* Maximum variation observed within the respective fields by hand harvesting.

Yield variations for these same six fields harvested by the plot combine are given in Table 3. Although the range in variation was about one-half that for the hand harvests, the same general trend was observed. Since the combine data are averages from 2 rows about 50 feet in length, or about six times longer, one would expect a lower amount of variation, strictly a function of sample size.

Comparisons of whole field yields with those obtained from hand harvests and the plot combine indicate that the plot combine is in general a better estimator than the hand-harvesting method. The range in yield between the plot combine and the whole field was 1 to 23 bu/a, whereas that between hand harvesting and the whole field was 7 to 47 bu/a. For this data set, the method of harvesting had no effect in the companies being able to meet the target yield for Phase III bond. However, for other cases not reported here, the plot combine produced higher yields than for the whole field, and this resulted in bond release; whereas, if only the whole field data were used, the target would not have been exceeded, hence bonds would not have been released. The data from either a plot combine or hand harvesting allows the use of statistical methods that in effect could allow bond release, as was the case for a few of these fields, even though the yield from the whole field was a few bushels per acre less than the target value.

Table 3. Variations in corn yield between strips collected with a plot combine.

Strip* No.	Field No. 1	2	3	4	5	6
	bu/a					
1	146	99	113	69	109	112
2	127	114	135	74	99	119
3	135	118	132	76	102	137
4	150	107	135	106	98	136
5	109	117	145	106	95	142
6	132	104	135	110	89	145
7	129	122	130	126	90	129
8	135	125	135	122	97	135
9	132	125	141	126	95	142
10	130	--	127	130	84	136
11	168	--	137	121	82	135
12	--	--	144	124	85	144
13	--	--	139	112	--	139
14	--	--	156	121	--	134
15	--	--	147	108	--	124
16	--	--	146	82	--	132
17	--	--	146	83	--	134
18	--	--	160	76	--	102
19	--	--	135	--	--	99
20	--	--	116	--	--	110
Mean from Combine	136	115	138	104	93	129
Max.**	29	26	47	57	27	46
Whole Field ave.	113	117	141	105	96	123

* Dashed line indicates strip doesn't exist.

** Maximum variation observed within the respective fields by hand harvesting.

Variations in yield for the first 20 observations from the first six strips harvested for field 1 are given in Table 4. This represents only about 1/3 of each of these strips, but in all cases includes the maximum variation occurring within these strips. The range in yield variation within strips was 39 bu/a. This variation is more likely a result of variations in soil properties; whereas, variations between fields, in addition to soil properties, include soil replacement methods, soil depth, and perhaps climate, as these fields are as much as 40 and no closer than 20 miles apart. In all cases, the same corn variety was used and essentially the same amounts of fertilizers.

Variations as a function of the method of mining were considered in this study but consistent trends were not observed. Yield data were collected from all 24 fields listed in Table 1, but all of these data are not shown here. There was a trend for less variation from end-dump trucks, but this was not significant. This lack of significance may be related to differences in yields occurring over time as a function of the growing contitions, as will be briefly discussed later. A significant difference was observed between methods of soil replacement. However, since the soils being replaced were not the same soil series for most of these comparisons, it was impossible to determine if differences were a function of mining method of a result of different soil types, hence these data are not shown. In other words, differences in yield would be expected as a function of the soil material that was replaced, its location on the landscape, and associated effects of climate over the growing season when the yields were measured.

Table 4. Variation in corn yield within strips collected by combine - Field 1.

Sample*	Strip No.					
No.	1	2	3	4	5	6
	bu/a					
1	124	110	124	142	95	148
2	143	118	120	142	118	113
3	146	113	111	149	123	133
4	157	128	133	133	137	153
5	140	122	132	160	139	150
6	140	107	135	172	134	157
7	136	125	120	178	103	156
8	143	130	156	178	107	149
9	145	115	145	155	112	134
10	153	135	146	142	95	143
11	153	144	121	114	119	129
12	143	145	123	143	120	146
13	167	156	140	156	98	119
14	174	158	150	172	105	152
15	171	156	157	146	123	123
16	206	149	154	180	99	85
17	190	119	128	175	95	72
18	180	153	126	152	83	95
19	146	135	128	161	113	106
20	127	135	145	158	99	120
Mean	136	115	138	104	93	129
Max.**	82	48	46	66	56	85

* Listed is only the first 20 observations within each strip.

** Maximum variation observed within the strip.

Variations between strips for three consecutive years are given in Table 5. The maximum of 69 bu/a variation between strips occurred in 1991, which also had the lowest average yield of 85 bu/a. Variation in means between years was 70 bu/a between 1991 and 1992. The target yield for this mine is 107 bu/a, and it is obvious that two of the three years this value was exceeded, with a three-year average of 127 bu/a. Although the same corn variety was not planted in the third year, in other tests these two varieties produced essentially the same amount of corn. It is likely that the reason for the lower yield in 1991 was the result of excessive moisture in July, which resulted in a nitrogen loss; and top dressing was not possible after that time as the corn was too tall.

Table 5. Variations in corn yields over three consecutive years for reclaimed prime farmland from Field 7.

Strip No	Year 1990	Year 1991	Year 1992
	bu/a		
1	149	86	134
2	147	83	152
3	137	80	149
4	141	92	149
5	139	101	162
6	118	92	147
7	136	86	163
8	152	132	182
9	159	67	122
10	136	63	168
11	142	73	174
12	140	64	156
Mean	141	85	155
Max.*	41	69	60

* Maximum variation observed within the strip.

Variations within strips harvested in two non-mined corn fields are given in Table 6. The yields represent only the first 20 observations of the strips harvested. Although each field was greater than 80 acres in size, the strips given here only underestimated the whole field by 3 bu/a in each case. Variations within these strips ranged from 21 to 51 bu/a for field 8 and 28 to 92 bu/a for field 9. This range is similar to that observed for reclaimed fields as well as that given in Table 4. In field 8, two soil series occur, Karnak and Waverly; whereas, the entire field 2 is mapped as Karnak. However, for field 9, the soil was designated as a silt over-wash phase. Both soils are similar and occur in an alluvial position associated with the Green River Basin in Kentucky. The 50 bu/a difference between the two fields is likely the result of different varieties being used as well as nitrogen rates, the planting date, and perhaps texture of the soil, and in all cases favored field 9.

Attempts to relate crop yield variations within a field to soil properties have not proven to be successful with the present data base (Data not given this paper).

Soybeans

Variations in soybean yield are given in Table 7. On a percentage basis, these variations were greater than those observed for corn. The largest variation was for field 10 which equalled 72.7%, with the lowest variation being 47% for field 2. This compares with corn, which had the largest variation of 55% for field 4 (Table 3), with the lowest variation being 21% for field 1. This was somewhat surprising, since the area harvested for soybeans was approximately six-fold larger. The likely reason for a larger variation for soybeans is that all of these data were collected the same year (1990) and a below average rainfall occurred in August/September that may have depressed soybeans to a greater degree than for corn which has a deeper rooting depth. Caution should also be exercised due to the lower number of soybean observations.

Table 6. Variations* within three strips collected from two non-mined fields in western Kentucky.

Sample/	Field 8			Field 9		
Strip No	1	2	3	1	2	3
	bu/a					
1	128	143	112	203	192	222
2	109	120	136	159	174	173
3	117	126	110	196	166	158
4	125	112	130	237	184	174
5	126	109	135	145	185	185
6	130	103	129	169	175	173
7	123	92	128	185	172	177
8	127	102	129	164	183	181
9	126	116	132	170	171	175
10	125	124	129	166	184	176
11	126	133	125	184	172	176
12	126	130	125	168	182	178
13	126	133	126	188	180	184
14	125	130	128	183	164	180
15	125	127	114	177	183	167
16	126	125	105	205	180	173
17	125	128	101	177	176	182
18	129	130	126	182	171	180
19	122	121	122	156	175	167
20	123	123	132	149	186	182
Mean	124	121	123	178	178	178
Max.**	21	51	34	92	28	64

* Data include variations for only the first 20 observations.
** Maximum variation observed within the strip.

Wheat

Variations for wheat yields are given in Table 8. The maximum variation of 64% was observed for field 14 (1991), whereas, the lowest variation of 20% occurred for field 13. This was in the same range as corn which was 55 and 21%. The data given in Table 8 represents two years; yields for fields 13 and 14 were from 1992 measurements, whereas the remainder of the fields were harvested in 1990. Note that yields were collected two times from field 14, but the area was expanded in 1992 and harvested in a different direction, hence direct comparisons of strip yields are not possible. In 1990, the highest yield of 65 bu/a was observed in the same approximate location as the highest yield in 1992 of 85 bu/a, but the locations within this field for the lowest yields for respective years do not coincide.

Table 7. Variation in soybean yields among strips collected by a plot combine from three fields.

Strip No	Field No 10	11	12
	---------- bu/a	----------	----------
1	36	24	19
2	36	34	20
3	36	36	35
4	22	41	33
5	17	39	28
6	37	40	33
7	41	41	33
8	40	33	31
9	39	33	34
10	29	37	32
Mean Yield	33	36	29
Max.*	24	17	16

* Maximum variation observed within the strip.

Table 8. Variations in wheat yields among strips collected by a plot combine from five fields.

Strip* No	Field No 13	14**	14**	16	17	18
	---------- bu/a	----------	----------	----------	----------	----------
1	60	88	36	39	49	41
2	63	75	44	43	46	53
3	59	76	45	40	46	39
4	69	76	58	41	43	47
5	68	84	45	42	36	37
6	70	76	56	41	41	39
7	61	71	38	42	40	46
8	71	65	38	42	39	50
9	72	64	39	42	37	44
10	70	65	37	36	43	44
11	72	68	42	50	39	43
12	68	72	41	39	43	--
13	66	75	65	41	36	--
14	70	68	52	43	36	--
15	66	81	--	45	34	--
16	66	71	--	41	--	--
Mean	67	73	45	41	40	44
Max.***	13	24	29	14	15	16

* Dashed line indicated strip does not exist.

** Data collected in 1992 and 1990, respectively.

*** Maximum variation observed within the strip.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

ILLINOIS CROPLAND REVEGETATION SUCCESS REQUIREMENTS

J. S. Lohse[1]

ABSTRACT

Under the Surface Mining Control and Reclamation Act of 1977, the mining industry is required to replace prime farmland to its pre-mining level of productivity. In Illinois, the Illinois Department of Agriculture is charged with the responsibility of developing methods to assess the productivity capacity of reclaimed mined land. The Agricultural Lands Productivity Formula was adopted in 1986 after extensive testing and evaluation. Software packages for the PC became an integral part of the program. The Department is currently evaluating the correlation between hybrid varieties and reclamation methodologies, and intends to pursue adoption of a new reference area concept.

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INTRODUCTION

Under SMCRA, the mining industry is required to replace mined prime farmland to its pre-mining level of productivity. In Illinois, the Illinois Department of Agriculture (IDOA) is charged with the responsibility of developing methods to assess the productive capacity of reclaimed mined land. In 1986, the Illinois Agricultural Lands Productivity Formula (ALPF) was adopted as a viable method of determining productivity restoration requirements on cropland. The ALPF, since its adoption, has undergone considerable testing and modification. These changes considered all aspects of management differences between mines, weather, reclamation requirements, and manpower training and office support from the Illinois Agricultural Statistics Service.

The original ALPF was published in 1985 (Lohse, et al.) and underwent several changes in application of the sampling procedures, methods for yield calculations, integration of federal agencies into the program, and training of support personnel. Since 1985 two addendums have been added to the Formula, one to correct an error in the hay formula and one to allow for row spacing differences in small grain crops.

Background

The original ALPF was developed over a period of seven years, starting in 1979 after the passage of SMCRA and the publication of the Federal Permanent Program Rules and Regulations (Federal Register, 1979), and continuing through 1984 with the final product. However, even with all the field testing, input from state university personnel, federal agencies, industry, and private organizations, the ALPF was not complete.

The original sampling procedures reflected the sampling scheme used by the USDA Agricultural Statistics Service in Washington, D.C. and the Illinois Agricultural Statistics Service. Beginning in 1982, crop sampling was done using federal procedures developed through 50 years of application and testing by federal agencies. However, after several years of testing, it became apparent that a new sampling procedure, more attuned to mined land reclamation, was needed to reflect differences in reclamation techniques and the heterogenous nature of soil replacement.

In 1983, the sampling procedure used by USDA was plotted on mined land maps to determine how effectively the sampling procedure covered the reclaimed fields being sampled. The conclusions reached from plotting individual sample locations was that yield determinations by the USDA procedure were ineffective, since only ¼ of the field was sampled, i.e., all of the sample points fell in one corner of the field.

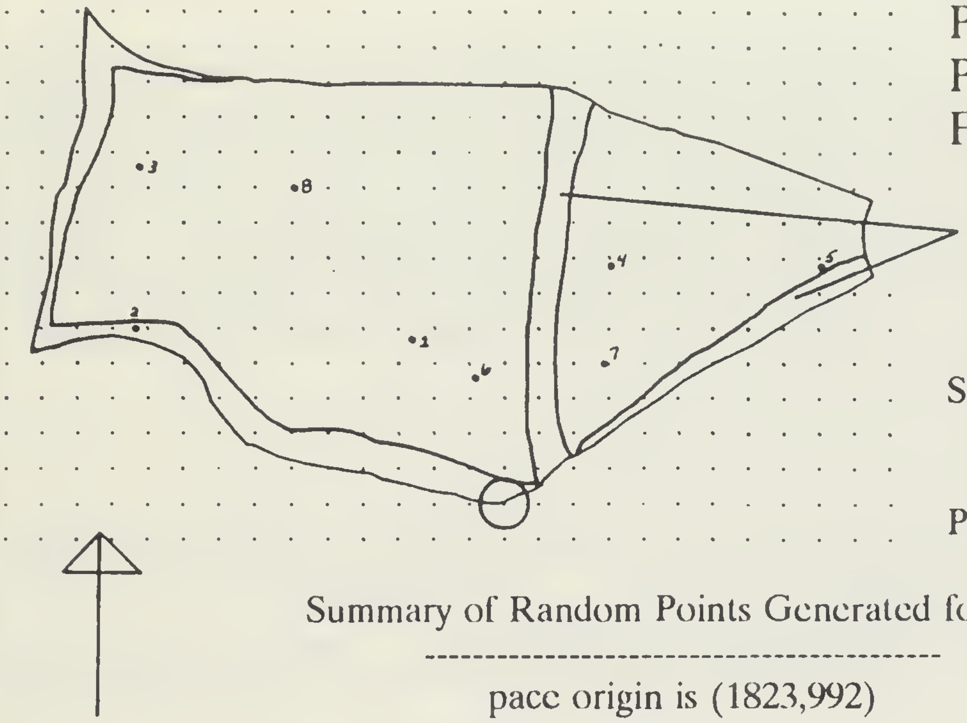
Starting in 1984, the IDOA, after studying several other yield sampling systems throughout the world, elected to go with a whole field randomized grid, whereby individual sample points were randomly picked by computer.

Since computer programs for use on PC's were practically non-existent, a contract was signed with a third party to develop a program to randomly plot sample points within field boundaries to be interactive with the AUTOCAD program used to digitize field boundaries.

The development of the MINEFIELD program allowed for the determination of field size (in acres), pace origin, pace distance (specified at 2.5 feet), edge distance (to eliminate edge effects on yield), map scale, addition of random points, printing of points, and creation of a script file to plot points within AUTOCAD on 100 foot grid intervals (Figure 1, Giordano, 1992). Since MINEFIELD serves more than one function, other individuals can use the areas subfile to plot fields, subsets of soil maps, and calculate individual and total acres of individual mapping units. The MINEFIELD program is used as a check against AUTOCAD to determine the number of acres in the field specified by the mining company. Discrepancies can be easily corrected within AUTOCAD (boundary point closure) or by calling the mining company.

Figure 1. Illinois Department of Agriculture sample enumerator field sheet.

Consol Coal
Burning Star 2
Pinckneyville 3
Permit 69/121
Field 3



Scale 1" = 400'

Pace origin = 1823,992

Summary of Random Points Generated for .dxf

pace origin is (1823,992)

1	Paces:	-105	W,	187	N	feet:	263	W,	468	N
2	Paces:	-413	W,	199	N	feet:	1033	W,	498	N
3	Paces:	-409	W,	383	N	feet:	1023	W,	958	N
4	Paces:	123	E,	271	N	feet:	307	E,	678	N
5	Paces:	363	E,	271	N	feet:	907	E,	678	N
6	Paces:	-33	W,	143	N	feet:	83	W,	358	N
7	Paces:	115	E,	159	N	feet:	287	E,	398	N
8	Paces:	-237	W,	359	N	feet:	593	W,	898	N

Plotting of sample locations, tabulation of paces and feet, and presentation of the output on paper allows agricultural statistics enumerators to properly locate and sample any given field or crop. The plot diagram occasionally indicates a discrepancy between the original submittal by the mining company and what was actually planted in the field. Examples include crops planted on less area than shown on field plots or yield data unrealistically high, due to planting of excluded areas such as conservation terraces and grassed waterways. Both of these problems can be corrected when yields are calculated. Acres can be added or subtracted to reflect actual crop yields.

IMPLEMENTATION

Since the inception of ALPF, certain logistical problems had to be overcome. The first was acquisition of equipment and manpower, and the second was field training of the staff in these new sampling procedures.

The Illinois Department of Agriculture was familiar with sampling procedures, in general, but additional field testing and training was necessary to convince the mines that the developed sampling procedures would reflect whole field harvesting done by the mines.

Site-specific fields were sampled, yields calculated, harvest losses considered, and results compared to machine combined field results. Both the IDOA procedures and the machine yields were statistically the same, namely, the yields were not significantly different. In most cases the yields were the same.

Additionally, training in the sampling procedures, adopted from the Illinois Agricultural Statistics Service and modified by IDOA, was necessary to make sure that each individual sampled the same crop in exactly the same manner. Noted, early on, was a yield difference in small grains between cutting down two rows and three rows of grain. With 3 rows, the yield results did not reflect field conditions (3.24 square foot sampling area). As fields grew in number and acres, IDOA personnel could no longer manage to sample all of the field requests by the mines. Table 1 shows the progressive increase in total number of fields and acres sampled between 1982 and 1992.

Table 1. Progressive growth of field crop sampling in Illinois.

	Total Number of Fields				Total Number of Acres				Total
Year	Corn	Beans	Wheat	Hay	Corn	Beans	Wheat	Hay	Acres
1982									0
1983	4	4	15	0	100.0	125.0	121.0	0	346.0
1984	1	1	24	0	10.0	1.2	178.1	0	189.3
1985	11	1	31	5	193.05	53.61	798.0	362.0	1406.66
1986	16	1	12	5	340.25	90.75	448.95	148.52	1028.47
1987	19	6	35	49	744.7	127.4	833.6	1339.6	3045.3
1988	28	8	29	42	1150.6	312.9	908.7	1211.13	3583.33
1989	59	21	47	60	1404.66	938.3	1064.2	1986.1	5393.26
1990	59	7	59	37	1601.2	276.0	1682.2	1137.17	4696.57
1991	118	23	41	48	3869.9	453.9	1343.8	1563.83	5044.87
1992	134	33	23	71	4544.4	951.8	822.5	1589.0	7907.7

Beginning in 1986, with the incorporation of the ALPF into Illinois Administrative Code (Illinois Register, 1986), IDOA began contracting with the Illinois Agricultural Statistics Service to do all field sampling and crop testings. This created new challenges since more people required training in our testing procedures, both by crops and by acceptable sampling methods within individual crops.

Each year, in the spring and mid-summer, IDOA participates in training sessions with agricultural statistics employees to explain differences between their sampling program (USDA's) and ours (IDOA's). These differences may include use of moisture probes and test equipment, importance of row spacing in small grains, or application of the five foot rule to rowcrops.

SAMPLING PROCEDURES

Corn, Soybeans, and Wheat

Rowcrops are essentially all harvested in the same manner, allowing for differences between crops. Each crop has a designated row length specified in the formula, each crop incorporates the five foot rule, each crop is harvested for all grain within a specified row length for a weight determination, and each crop has the average row spacing determined across a 5-row spacing. Each crop has a fixed number of sample points based on the number of acres in the field. The original sampling table (Lohse, et al., 1985) has been modified by incorporating additional sample points to reduce some of the statistical variability within fields. In addition, fields of less than 10 acres are harvested in their entirety to reduce the labor intensity of sampling small plots. Exceptions can be obtained to the 10 acre rule by mining companies for specific management problems. These problems may include planting of two fields side-by-side as if the area were one field; lateness of the harvest season, where inclement weather would preclude the mine from harvesting the crop before the ground froze or the crop germinated in the seed heads; or the inability of the mine to harvest the crop though normal means.

The original sampling procedures did not consider any bias that might be shown by the field personnel. Individuals tended to extend or reduce the pace length to avoid bad areas in the field, i.e., area not planted, area containing erosion problems, poor germination, etc. To eliminate this problem, IDOA adopted the 5 foot rule from ag stats. At the last step of the pace count, a flag or measuring stick is placed at the toe of the final step and 5 feet are measured off before sampling can begin. At the end of the 5 foot distance, the sampling bar is placed perpendicular to the end point. The row distance is taken to determine which of two sampling procedures to use (row spacing or broadcast). For row spacings of less than 8 inches, a broadcast procedure is used, and all grain within a 3.24 or 9 square foot area is sampled for wheat or soybeans, respectively.

For row spacings greater than 8 inches apart, 2 rows of wheat or 2 rows of soybeans are harvested. For wheat, each row is 21.6 inches (1.8 feet) long. However, for soybeans, 1 six foot row is harvested based on 2 three foot bar lengths. All of the wheat heads are clipped 1/2 to 1 inch below the base of the head, placed in a sample bag (paper), labelled, and mailed to IDOA for processing. Soybeans are harvested by removing the entire plant or by picking each pod from every plant, placed in a sample bag, labelled, and mailed to IDOA. For both of these crops, all grain which falls on the ground is picked up and added to the sample bag.

This results in a 100 percent pick of the sample area and necessitates the use of a statewide harvest loss adjustment for each sample point.

Problems do occasionally arise from differences in sampling procedure between USDA personnel and IDOA. On drilled rows for wheat and beans, where rows are discernible, the field may be harvested based on row width (distance between rows). If the rows are discernible, but less than 8 inches apart, the sample point should be harvested by area, not row width. When this procedure is not followed, the yields may be unreasonably high and may require the mine to verify the high yields by whole field harvest.

For whole field sampling of corn, wheat, and soybeans, scale tickets are collected by field enumerators. The scales used for weighing must be state certified within the last 12 months to ensure accuracy. The field moisture must be stated somewhere on the scale tickets or on the sample sheets for each field. This information is then mailed to IDOA for processing.

Corn is harvested based on 15 foot of row. The third and fourth ears are tagged, at time of harvest, for shipment to IDOA. Ears must have at least one kernel of corn to be considered. If the third or fourth ear is not developed, then the next ear is labelled. All corn ears, within the 15 foot row, are harvested and weighed. As with wheat and soybeans, the row distance across 5 row spaces is measured and recorded. Each individual sample is hauled to the edge of the field for processing. Thus, each 15 foot row sample is weighed, the marked ears are wrapped in plastic sample bags, labelled with the sample number, and mailed to IDOA.

Hay

Hay sampling poses some unique problems due to the multitude of sampling procedures for handling this crop. Hay can be baled (round or rectangular), green chopped, or hand harvested. Handling hay can be labor intensive, as in hand sampling, or relatively easy (bales). Rectangular bales can be hand weighed (no state certified scales nearby) or hauled (round and rectangular) to state certified scales. Green chopped hay must be tested for moisture within 30 minutes of cutting to avoid deterioration of the sample. Hay can be sprayed with a preservative and baled at a higher moisture content, or if not sprayed, hope for ideal weather and drying conditions prior to baling.

Hay, in Illinois, is normally baled in round bales of 600-1500 pounds or rectangular bales of 50-90 pounds. For round bales, the field enumerator(s) count all bales in a designated field, randomly tag 5 bales, and have these 5 bales weighed on certified scales. If there are fewer than 5 bales harvested, then all of the bales are weighed. If a field has a partial bale, then any partial bale is weighed separately and reported on the field sheet. Five moisture readings and one temperature reading are taken on each of the 5 bales using probe instruments and recorded. Rectangular or square bales may be either individually weighed or weighed as a unit. One unit consists of 20 bales or 10 percent of the total bales present, whichever is less. Each hay yield cutting, by field number, is calculated and summed over all cuttings to determine the total production result.

REPORTING REQUIREMENTS

All results of field sampling are reported to individual mining companies (for their own fields), to their corporate or management groups, and to the regulatory authority. Summary sheets for each field will indicate harvest results, weight of grain before and after shelling, moisture content, and row spacing or area occupied by the sample. For corn, the weight of corn from the 15 foot row is also shown. With hay, only the tons per acre is shown.

At the end of each cropping season, normally late fall, the statewide harvest loss, as determined by the Illinois Agricultural Statistics Service, is compiled. The harvest loss is subtracted from each sample point for the respective crops. The harvest loss is excluded from the result where whole field sampling was done since the efficiency of the combine determines its own harvest loss. The harvest loss for each crop is transmitted to the regulatory authority, and to mining companies on request.

Formula Run

From January through April of each year, the county average for each crop is tabulated for corn, soybeans, wheat, and hay. These production figures (total bushels by crop or total tons for hay in county), yields, and acres harvested for grain are entered into the Illinois Agricultural Lands Productivity Formula along with the acres in production by county (soil type) to determine a final county success factor for each crop. The county success factor reflects differences in weather variability between and within counties, yield differences for each soil type mapped in the county, and management differences between farm operators. This factor is used to determine the yield standard, success or failure, which must be met for proof of productivity.

Sample Tracking

Beginning in 1983, the IDOA began tracking the success rate of individual fields by mining company. These summary sheets indicate individual mining companies, mine name, permit number, total acres, target yield, average yield per field for each year, and the success or failure of a given crop. This spreadsheet indicates which crops have passed and the year the crop was successful. Use of this table effectively eliminated duplication efforts by the mine to grow the same crop more than once and allows Illinois Department of Mines and Minerals to determine whether a given field is eligible for Phase II bond release. Mining companies were asked to eliminate those fields where crops had passed in prior years or where only one crop, such as corn, was still required. If corn was the last crop to be grown, and the mining company was proposing a different crop, then productivity testing is denied by the regulatory agency unless the crop is changed to one required for productivity testing. An exception for duplication of crops is allowed when fields have been augmented between the first and second crop.

In Illinois, if hay has passed prior to augmentation, that crop is counted as part of the total production requirements for the field. Augmentation may not only be deep-ripping of the field, but may include major erosion and gully repair. Repair of minor gullies is normally considered a part of the farming operations, when the area is small relative to the whole field, erosion is not expected to re-occur, and the area is stable [62 Illinois Administrative Code Section 1816.116 a)2)E)]. Also allowed, as part of the normal farming operations, is deep-ripping to a maximum depth of 18 inches.

FUTURE CONSIDERATIONS

Recent research done by the University of Illinois and the University of Kentucky (Dunker, et al., 1992; Barnhisel, et al., 1992) has indicated that drought tolerance by different rowcrop genotypes produces different results relative to yield. Results for some of these hybrids have been summarized for Illinois at site specific locations. In order to facilitate the dissemination of this information, the IDOA is undertaking a survey, starting with the 1992 cropping season, to correlate crop varieties (hybrid number) with root media replacement methodology, topsoil replacement, and type of deep tillage equipment used under Illinois growing conditions (Table 2). Information to be supplied by the mine(s) will include the seed brand (Pioneer, Funk, DeKalb, etc); hybrid number; root media (reclamation replacement method, e.g., scraper haulback, dragline, cross-pit conveyor, etc.); topsoil handling (windrow, truck-shovel, scraper placed, etc.); and deep tillage (TLG-12, Tiger II, DMI, etc.) (Table 3).

The Illinois Department of Agriculture will correlate and summarize this information each year and supply the yield data for different crops to allow all mines to make the best management decisions relative to planting crop varieties. Since IDOA is a neutral advisor in this process, a disclaimer will be added to the report to eliminate bias toward any seed company or genetic line.

SMCRA allows the use of reference areas, to be used as a check against mined ground, for proof of productivity. However, these reference areas can only be on adjacent unmined ground of similar soil types. The IDOA has undertaken the consideration and development of the reference area concept in a slightly different light. The IDOA would like to use mined ground as a reference area, provided the reference field has met all criteria for bond release using the ALPF. Though this concept is in the developmental stage, the application would allow the mines to compare similar reclamation standards and similar mixtures of soils, in close proximity, to their current revegetation requirement fields.

Table 2. Proposed survey form.

Illinois Department of Agriculture
1992 Crop Season
Mine Yield Reclamation Project

MYRP	Crop Year	Company Name	Mine Name	Pit Name	Yield	County	Field No.	Class	Crop Planted	Seed Brand	Hybrid Number	Root Media	Topsoil Handling	Deep Tillage
500	92	Amax Coal	Delta Mine	C & H East		Williamson	P409	High	Hay					
501	92	Amax Coal	Delta Mine	C & H East		Williamson	P412	NCC	Hay					
502	92	Amax Coal	Delta Mine	C & H East		Williamson	P413	High	Hay					
503	92	Amax Coal	Delta Mine	C & H East		Williamson	P416	High	Hay					
504	92	Amax Coal	Delta Mine	C & H East		Williamson	P417	High	Hay					
505	92	Amax Coal	Delta Mine	C & H East		Williamson	P418	High	Hay					

Table 3. Coding requirements for Table 2.

Root Media Reclamation Systems		Deep Tillage		Topsoil Handling	
SCR	Scraper Haul	TLG	TLG-12	SCR	Scraper Placed Topsoil
BTRK	Bottom Dump Truck	SLP	Slip Plow	WDZ	Windrowed with Dozer
RTRIC	Rear Dump Truck	DMI	Deep Plow (48")	WCS	Wheel Conveyor Spreader
CPW	Cross Pit Wheel	DM3	Deep Plow (30")	BTRIC	Bottom Dump Truck
WCS	Wheel Conveyor Spreader	RKP	River King Plow (20")	RTRK	Rear Dump Truck
DL	Dragline	RM1	Harry Jones		
		HOL	Holloway		
		CHS	Chisel Plow (9")		
		TG2	Tiger II (16")		
		MLD	Moldboard Plow		

SUMMARY

Since the original publication of ALPF in 1985, the IDOA program has undergone growing pains and adjustments to different cropping and/or management conditions. This program is in a state of dynamic equilibrium, ever changing to allow for future development concepts. The IDOA is proud of its program and feels it has been and will continue to be effective in protecting the integrity of agricultural resources impacted by mining operations.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

COMPACTION AMELIORATION ON SOIL PROPERTIES AND CROP YIELDS FROM RECLAIMED MINESOILS

K. C. Vining and S. A. Schroeder[1]

Traffic during reclamation of minelands can create compacted zones which inhibit root development and affect plant productivity. Experiments to investigate the impacts of compaction on plant growth were performed at two western North Dakota minesites reclaimed using accepted reclamation procedures. Treatments consisted of surface applied chisel (0.15 m depth) and subsoil (0.6 m depth) tillage and strips of six forages and a small grain planted perpendicular to tillage in split plot designs. Measurements of soil physical properties made during the 4-year period 1989 to 1992 indicated reduced bulk densities and soil penetration resistance in the subsoiled treatments to the depth of subsoil tillage. Yields of small grains and forages measured during this period were variable and reflected the patterns of weather experienced during the growing seasons. Forage yields were generally greater from the subsoiled treatments although differences between tillages were insignificant. Even though the effects of subsoiling on soil physical properties remained evident during the 4-year period, it appeared as if weather variability was the dominant factor which influenced crop and forage yields at the experimental sites.

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INTRODUCTION

Agricultural production in western North Dakota is affected more by weather and water availability than perhaps any other factors. Rainfall is often sparse and scattered. Strong winds rapidly dry the soil and can dessicate crops. Adequate soil preparation to maximize water infiltration and preserve soil water is a prime concern for producers.

Coal mining companies must also be concerned about soil preparation and revegetation due to the SMCRA laws of 1977. Reclaimed land must be as productive as the land was prior to disturbance. However, reclamation procedures and traffic from heavy equipment can create layers of compacted soil which may impact crop production. Water movement into reclaimed soils in North Dakota is often slower than into comparable undisturbed soils due to disruption of pore continuity during soil replacement (Potter et al., 1988). Smaller crop yields may then be produced from reclaimed soils during years of low or poorly distributed rainfall (Schroeder and Halvorson, 1988).

Tillage has been used to improve the conditions of soils. Schroeder (1988) compared the effects of various tillages including subsoiling on soil bulk densities of reclaimed minesoils in North Dakota and found few statistically significant differences. Results were attributed to recompaction during seedbed preparations. Bennie and Botha (1986) found that subsoiling may enhance water availability and root growth leading to increased crop productivity. Vining and Schroeder (1992) found that water use and yields of spring wheat (*Triticum aestivum*) were similar between surface-applied chisel and subsoil tillages because of limited precipitation and soil water recharge. However, Ide et al. (1987) have shown that soil condition and crop yield benefits from subsoiling may persist for at least five years depending upon soil types and climatic conditions.

This paper presents an investigation of the time effects of surface-applied tillage treatments on the physical properties and crop yields from reclaimed minesoils.

MATERIALS AND METHODS

Research sites were established in May, 1989 at the Basin Cooperative Services Glenharold Mine southeast of Stanton, ND and at the Knife River Coal Mining Company South Beulah Mine south of Beulah, ND. The soils had been respread the previous autumn. Each site was located on nearly level land and was about 0.5 ha in size. The general texture of the soils at Glenharold and Knife River were loam and sandy loam, respectively.

Surface tillage treatments applied to each site consisted of chiseling (0.15 m depth, 0.3 m spacing) and subsoiling (0.6 m depth, 0.6 m spacing). Each treatment was applied randomly in two strips each 12.8 m wide along the length of the sites. The sites were fertilized (168 kg ha^{-1} 10-50-0 at Glenharold; 207 kg ha^{-1} 20-90-20 at Knife River), then disked and harrowed. Each site was divided into two equal blocks perpendicular to tillage. Six crop strips, consisting of (1) alfalfa (*Medicago sativa*); (2) native mix - western wheatgrass (*Pascopyrum smithii*), green needle (*Stipa viridula*), big bluestem (*Andropogon gerardii*), slender wheatgrass (*Elymus trachycaulus*), side-oats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*); (3) precrop mix - alfalfa, smooth brome (*Bromus inermis*). pubescent wheatgrass (*Thinopyrum intermedium subsp. barbulatum*), tall wheatgrass (*Thinopyrum ponticum*); (4) pubescent wheatgrass; (5) small grain ('Stoa' spring wheat); and (6) tall wheatgrass were planted in each block perpendicular to tillage. Small grain strips were chiseled in autumn, then disked, and fertilized as needed for a 2.7 Mg ha^{-1} yield, in the spring prior to planting.

A penetrometer was constructed in 1990 to measure soil strength based on the device designed by Hooks and Jansen (1986). A 30° cone with base area of 506 mm^2 was attached to a 1 m long, 19 mm diameter rod which was pushed into soil hydraulically at a rate of 17 mm s^{-1}. Data were collected electronically on a Polycorder for direct transfer to a computer. Beginning in 1991, a smaller 285 mm^2 base area core and smaller 16 mm diameter rod were used to attain greater penetration depths.

Soil bulk density measurements were made at the time of neutron access tube installation in 1989, and in subsequent years during penetrometer measurements of soil strength. Measurements of rainfall were also made at each site. Both sites experienced below normal precipitation during every growing season (Table 1).

Forage and small grain yields were sampled by hand usually in June and August, respectively. Both forages and small grain were dried at 60° C for 48 h. Forages were weighed to determine dry mass yields, while the small grain was threshed and the kernels weighed to determine grain yield.

RESULTS AND DISCUSSION

Results from the analyses of soil bulk densities from the Glenharold and Knife River sites shows that the subsoiled treatments maintained generally lower bulk densities to the depth of subsoil tillage (0.6 m) throughout the years of study (Table 2). However, few significant differences between tillages were found for any year due to the large variability of bulk density values obtained from all the crop subplots. The general trend of bulk

Table 1. Measured growing season precipitation at the Glenharold and Knife River locations.

	Year			
Month	**1989**	**1990**	**1991**	**1992**
		(mm)		
		Glenharold		
April	----	12.2	37.6	15.5
May	21.6	39.1	53.3	23.9
June	29.2	137.4	97.0	44.4
July	32.0	49.0	33.8	75.4
August	50.5	19.8	24.4	32.0
September	13.2	46.7	30.0	33.0
October	----	10.4	14.7	0.5
Total	**146.5**	**314.6**	**290.8**	**224.7**
		Knife River		
April	----	15.2	43.7	19.0
May	19.1	58.2	46.7	20.3
June	31.5	136.7	64.3	56.9
July	41.9	32.3	6.9	46.7
August	52.8	10.7	56.9	30.0
September	10.9	33.8	24.6	16.5
October	----	9.7	6.9	0.5
Total	**156.2**	**296.6**	**250.0**	**189.9**

densities with time was toward larger values. The larger values which were calculated in 1990 have been attributed to the extremely dry soil conditions which existed during spring of that year.

Mean soil penetrometer cone indices from the Glenharold and Knife River tillage treatments are shown in Figure 1. Soil strengths have increased steadily during the past three years. In fact, most increases from 1990 to 1992 were statistically significant (P = 0.05). At each site, cone indices have remained lower in the subsoil treatment from the surface to nearly the depth of subsoil tillage throughout the length of study. Cropping patterns have also influenced soil strength. The growing of continuous small grains led to the lowest mean cone indices at all depths in these subplots at both sites by spring, 1992 (not shown) due perhaps to the regular annual patterns of tillage, and the introduction of soil organic material and biopores from rapid root growth/decay.

Mean crop yields during the past three years from the Glenharold and Knife River sites are shown in Figures 2 and 3, respectively. The greatest yields from most crops occurred in 1991, a year which had nearly ideal early season growing conditions. At both sites, the greater yields fluctuated between the tillage treatments, depending upon crop and weather variability. These results tend to reinforce the notion that weather and water availability are the dominant factors for crop production from these soils.

Table 2. Mean soil bulk densities by year and tillage obtained during neutron access tube installation (1989) and penetrometer measurements (1990-1992) from the Glenharold and Knife River sites.

Year	Tillage	Depth (m) 0-0.3	 0.3-0.6	 0.6-0.9	 0.9-1.2
		($\mathrm{Mg\ m^{-3}}$)			
		Glenharold[†]			
1989	Chisel	1.22a	1.42a	1.43a	1.57a
	Subsoil	1.16a	1.28a	1.43a	1.55a
1990	Chisel	1.41a	1.53a	1.60a	1.64a
	Subsoil	1.38a	1.49a	1.59a	1.71a
1991	Chisel	1.29a	1.47a	1.51a	1.61a
	Subsoil	1.19b	1.36a	1.52a	1.59a
1992	Chisel	1.28a	1.43a	1.49a	1.71a
	Subsoil	1.24a	1.47a	1.55a	1.61b
		Knife River[†]			
1989	Chisel	1.50a	1.73a	1.58a	1.59a
	Subsoil	1.47a	1.56a	1.55b	1.58a
1990	Chisel	1.72a	1.73a	1.72a	1.81a
	Subsoil	1.62b	1.70a	1.74a	1.80a
1991	Chisel	1.46a	1.64a	1.63a	1.64a
	Subsoil	1.45a	1.58a	1.61a	1.63a
1992	Chisel	1.52a	1.75a	1.62b	1.73b
	Subsoil	1.52a	1.75a	1.80a	1.88a

[†] For each year and depth at each location, values followed by the same letter indicate no significant difference between tillages (P = 0.10).

CONCLUSIONS

Soil conditions were improved (compaction reduced) by subsoiling, but the lack of water to percolate and be stored in the subsoiled treatments precluded the treatments from producing greater yields. The fact that the subsoiled treatments have shown reduced soil strengths and increased porosity (decreased bulk density) indicates that increased water percolation, water availability, and crop yields could occur after a period of above-normal precipitation.

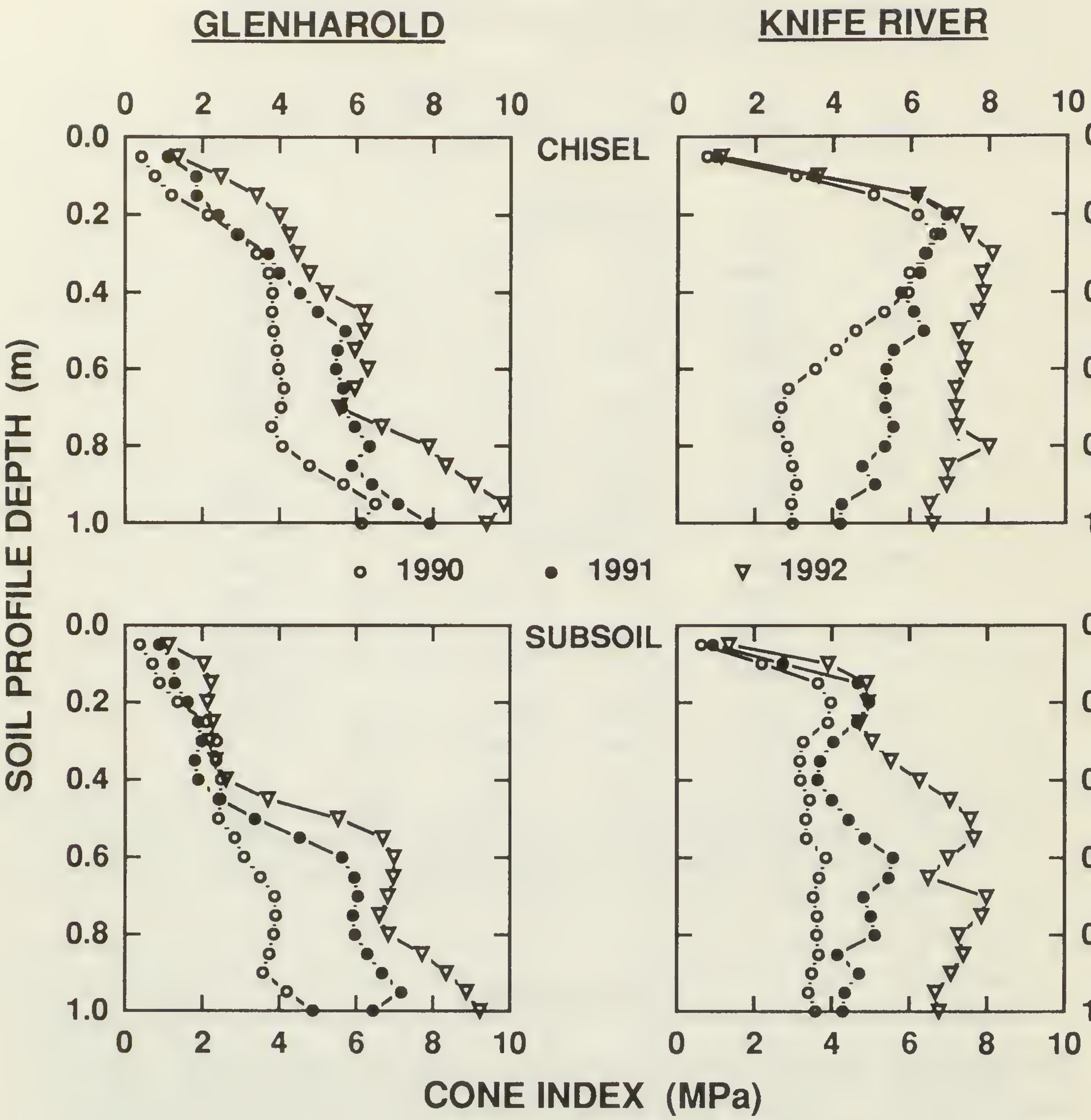

Figure 1. Mean soil cone indices by depth and tillage for the years 1990, 1991, and 1992 from the Glenharold and Knife River sites.

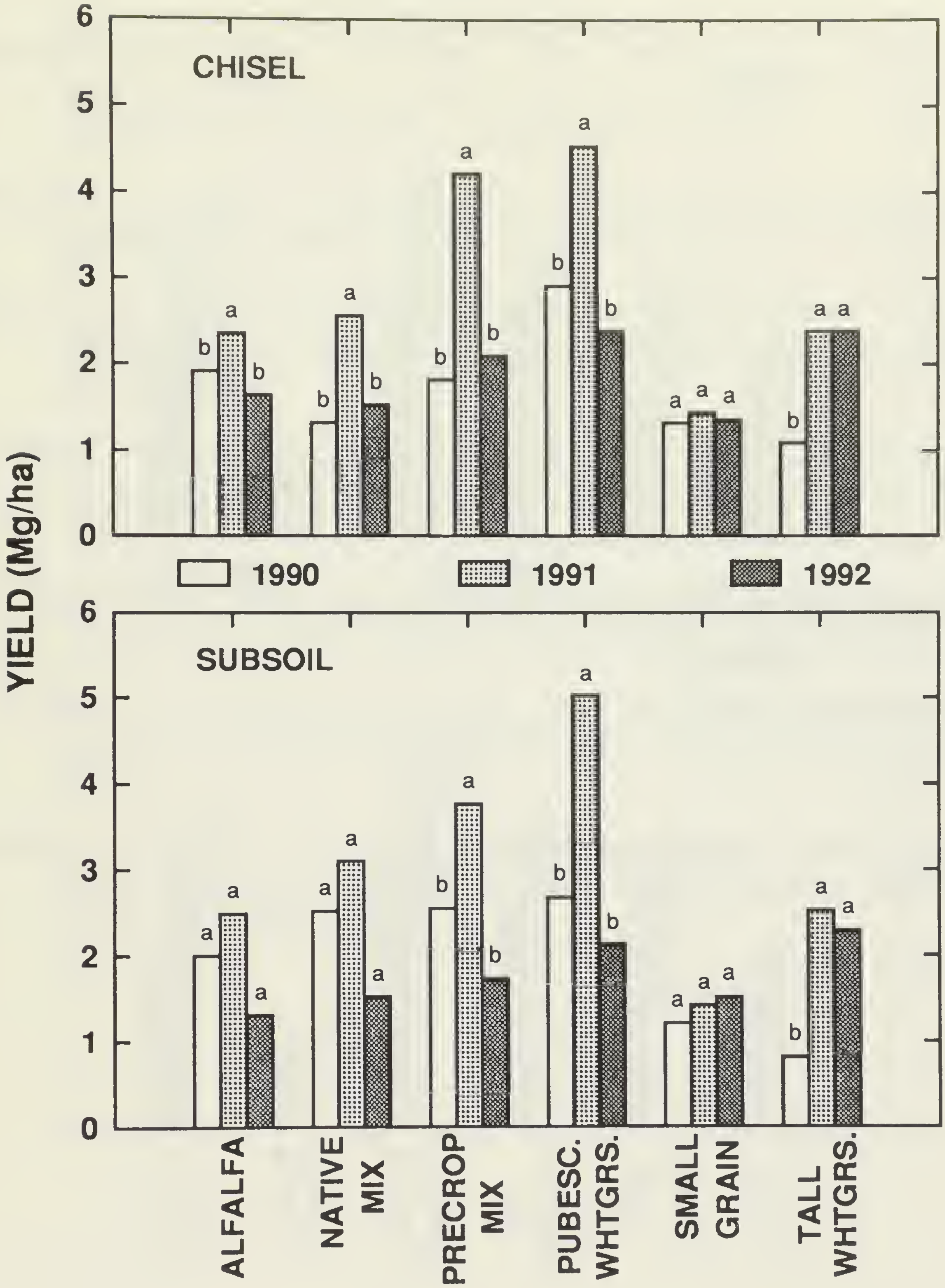

Figure 2. Mean forage and small grain yields by tillage for the years 1990, 1991, and 1992 from the Glenharold site. For each crop/tillage grouping, values with the same letter are not statistically different (P = 0.10).

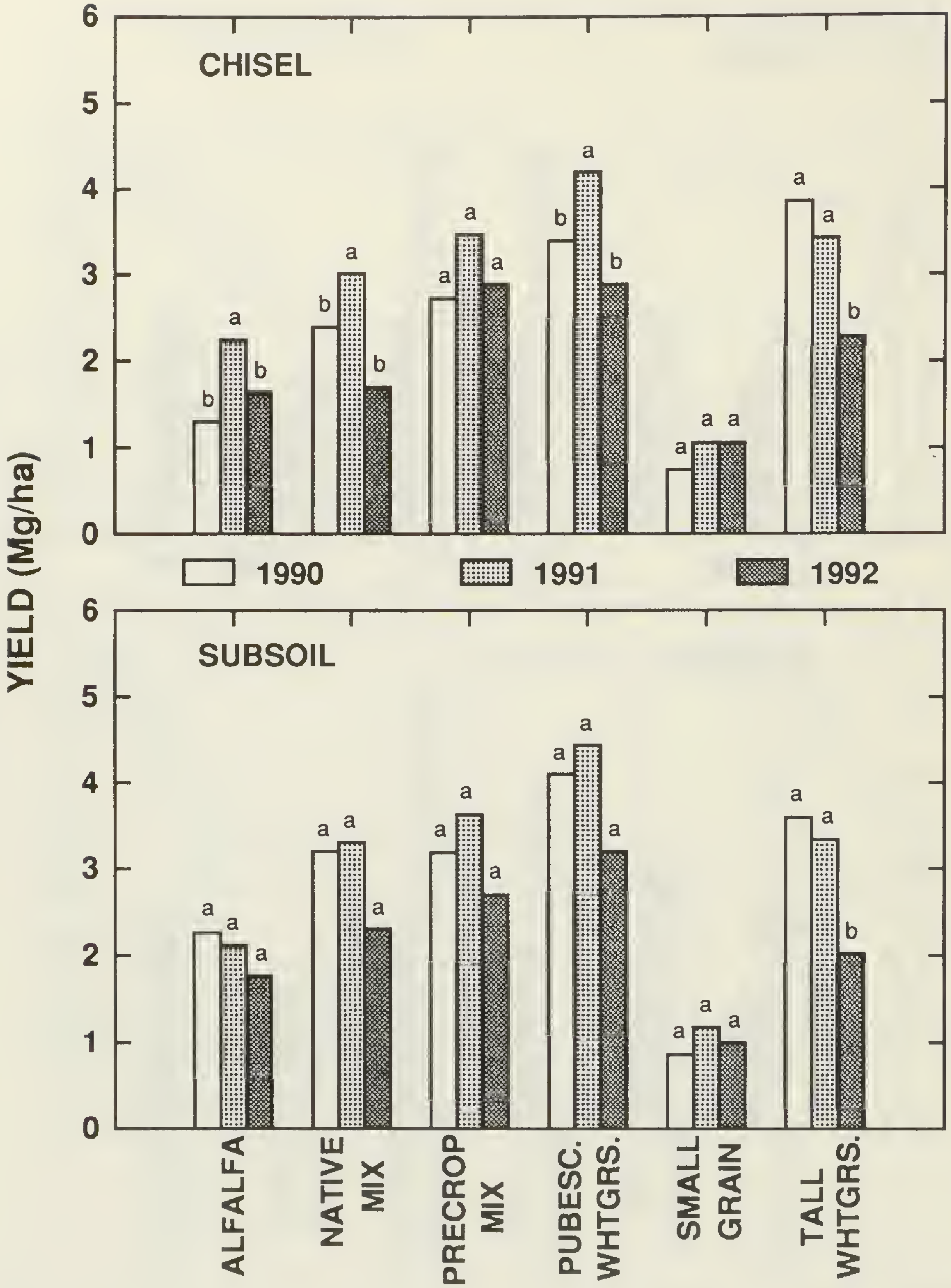

Figure 3. Mean forage and small grain yields by tillage for the years 1990, 1991, and 1992 from the Knife River site. For each crop/tillage grouping, values with the same letter are not statistically different (P = 0.10).

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Planning, Rehabilitation and Treatment of Disturbed Lands
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PRIME FARMLAND RECLAMATION RESEARCH AT THE UNIVERSITY OF ILLINOIS

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Abstract

Reclamation research of mined land to be used for crop production has been ongoing by the University of Illinois since 1977. Results of these studies has shown that poor soil physical condition is the most limiting factor to successful row crop production on mined land. Critical to success are selection of the best available soil materials used in soil construction and a material handling method which will minimize compaction. Excellent corn and soybean yields have been achieved on low soil strength soils in high stress as well low stress years. Total crop failures have occurred on high strength soils in years of weather stress. Deep tillage practices have been successful in improving compacted soils, but it is important to avoid compaction when the soil materials are handled. Soil strength measurements with a cone penetrometer has proven to be a useful tool in evaluating rooting media and reclamation practices.

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INTRODUCTION

The decade following the passing of PL 95-87 saw active research programs in several states to develop the technology needed for successful reclamation. In 1977 the University of Illinois with funding from five coal companies initiated a comprehensive research reclamation program. This initial program led to 10 years of research in which university, industry, and regulatory personnel worked side by side to identify and propose solutions to reclamation problems. Congressional action in 1986 established a five-year prime farmland reclamation program to assure continuation of two active prime farmland centers. This five year program is supported jointly by federal (80%) and industry (20%) sources. CSRS (The Cooperative States Research Service in USDA) is administering the program and selected the University of Illinois and the University of Kentucky as the centers.

The purpose of this review paper will be to report and summarize to date research work in Illinois concerning rowcrop response to various reclamation practices. Discussion of results will focus on reporting yield responses, observations, and summary to date from the Illinois work. There will be little attempt to distinguish between prime and non-prime farmland, even though prime farmland is addressed separately in federal legislation. The principles of reclamation for rowcrops, and to a large degree, the potential for success are quite similar for prime and non-prime farmland. Most prime farmland must by law be reclaimed to row crop capability, but not all row crop reclamation is on prime farmland.

SELECTION OF SOIL MATERIALS

Segregation and replacement of horizons from the premine soils is a practice that is required by law under many conditions. Early reclamation research was focused on the evaluation and characterization of selected soil materials to be used for soil horizon replacement or substitution, if the substituted soil material could be shown to be as productive as the natural soil horizon it replaced. Construction of minesoils with good quality soil materials and desirable physical properties is essential to attaining productivity levels necessary for bond release.

Greenhouse evaluation revealed that replacement or alteration of the claypan subsoils of southern Illinois would increase crop growth by enhancing the chemical and physical properties of mined land (Dancer and Jansen, 1981; McSweeney et. al., 1981). Topsoil materials generally produced somewhat greater plant growth than did mixtures of B and C horizons, but the B and C horizon mixtures were commonly equal to or better than the B horizon materials alone. The natural subsoils of this region are quite strongly weathered and acid, or are natric and alkaline (Snarski et. al., 1981). The alternative material mixed in or substituted was generally much higher in bases than the acid soils and lower in sodium than the natric soils. Liming and fertilizing of the soil horizon material produced a good yield response and reduced the need for material substitution. McSweeney et al., (1981) also got a favorable greenhouse response to blending of substratum materials with B horizon materials from the high quality Sable soils (Typic Haplaquolls) in western Illinois. This response to blending was less pronounced than that observed with materials from southern Illinois.

Most of the Illinois research has centered around field experiments to evaluate row crop response to soil replacement and various reclamation practices. Premine soils ranged from the highly productive deep loess soils developed under prairie vegetation (Mollisols) at the western Illinois sites to the lighter colored, more strongly developed Alfisols at the southern Illinois sites. Corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr) were grown on these newly constructed soils to evaluate productivity. Following up on the greenhouse studies, most of the early field studies addressed the issue of topsoil and subsoil horizon replacement.

Topsoil replacement has generally been beneficial for seedbed preparation, stand establishment, and early season growth when compared to graded spoil materials (Jansen and Dancer, 1981). Yield response to topsoil replacement has ranged from strongly positive to strongly negative. At the Norris mine in western Illinois, replacement of 45 cm of dark prairie topsoil over graded wheel spoil resulted in a significant positive corn yield response in three of four years with irrigation and two of four when not irrigated . Soybeans responded favorably to topsoil in one of the two years studied (Dunker and Jansen, 1987a). Significant negative yield responses to topsoil occurred in years of weather stress. Year to year variation in corn yield was considerably greater on the unirrigated topsoil than the unirrigated wheel spoil. Compaction caused by the use of scrapers to replace topsoil is assumed to be the reason for low topsoil yields in years of weather stress. The zone directly below the topsoil has a bulk density of 1.7 to 1.9 Mg m3 and very low hydraulic conductivity.

At the Norris topsoil wedge experiment, A horizon material was replaced over wheel spoil by scrapers in thickness ranging from 0 to 60 cm. There was a significant positive yield response to increasing topsoil thickness for corn, but not for soybeans . Year by year results showed positive relationships to topsoil thickness in years of favorable weather, but negative responses in years of moisture and temperature stress (Jansen et al., 1985).

At Sunspot mine, in western Illinois, topsoil and B horizon replaced over dragline spoil was evaluated over an eight year period. Soil treatments consisted of 38 cm of topsoil replaced over replaced B horizon; 38 cm of topsoil replaced directly over dragline spoil; 90 cm of B horizon replaced directly over dragline spoil; and dragline spoil only . Bulldozers pushed the soil materials onto the plot areas and it is important to note that scrapers were never allowed directly on the plots at any time during construction. An undisturbed tract of Clarksdale soil (Udollic Ochraqualf) was used as an unmined comparison. Topsoil replacement resulted in significantly higher corn yields in four out of eight years when replaced over B horizon materials and six of eight years when topsoil was replaced directly over dragline spoil (Dunker and Jansen, 1987b). Corn grown on the topsoil replaced treatments had a higher percent stand at harvest, had fewer barren stalks, and a higher ratio of shelled grain per total ear weight than corn on the non-topsoil treatments. Soybean yields were significantly higher on the topsoil replaced treatments in six of seven years whether or not B horizon materials were replaced. The topsoil/B horizon treatment produced corn yields comparable to the undisturbed Clarksdale in five of seven years while the B horizon treatment without topsoil produced corn yields comparable to the undisturbed in only one year. The dragline spoil was unable to equal corn yields in any of the years studied whether topsoil was replaced or not. Fehrenbacher et al., (1982) found that corn roots penetrated significantly deeper in the B horizon materials than the dragline spoil and that bulk densities were significantly higher in the graded dragline spoil than the replaced B horizon at a depth of 54 cm and deeper. Bulk densities between the B horizon material and the undisturbed Clarksdale were similar. It is not possible to determine whether the favorable response to the B horizon treatment was due to the B horizon material, or to the lower soil strength which resulted from the careful handling.

Response to soil horizon replacement in southern Illinois has been less dramatic than has been observed at the western Illinois sites. This is understandable considering that A horizons are more highly weathered and average 20-24 cm in depth compared to 40-45 cm in the highly productive western Illinois soils. At River King, in southern Illinois, topsoil replaced by scrapers over wheel spoil significantly increased corn yields in only one of eight years and soybeans in three of six . The River King site does have good quality spoil and rather mediocre topsoil.

Soil horizon replacement and thickness of soil materials from southern Illinois has been studied at the Captain mine where the natural soils have chemical and physical problems which limit productivity. The Captain wedge experiment was used to evaluate corn and soybean yield response to thickness of scraper placed rooting medium (0 to 120 cm thick) over graded cast overburden, with and without topsoil replaced . Yields of both corn and soybeans increased with increasing thickness of hauled material to about the 60-80 cm depth. Meyer (1983) found very few roots below the 60 cm depth and found that roots in the subsoil were largely confined to desiccation cracks. The subsoil physical condition can best be described as compact and massive with very high bulk density levels and poor water infiltration. These scraper built soils lack the macropore network needed to conduct water and to provide avenues for root growth. Corn yields acheived on these plots were equal to the permit target yield in only one of the twelve years studied (Dunker, et. al., 1992). Soybean response was similar with only one year in ten acheiving target yield levels.

SOIL PHYSICAL PROPERTIES

Poor soil physical condition has proven to be the most severe and difficult limiting factor in the reclamation of many prime farmland soils. Indorante et al. (1981), in a comparison of mined and unmined land in southern Illinois reported that reconstructed mine soils studied had higher bulk densities and they lacked any notable soil structure. Natural improvement in compacted mine soils is a slow process. Thomas and Jansen (1985) studied soil development in eight mine spoils ranging in age from 5 to 64 years looking at physical, chemical and micromorphological properties. All eight minesoils showed some evidence of soil development, but depth of structure development ranged from only 3 cm at the 5 yr old site to 35 cm at a 55 yr old site. No evidence of clay translocation attributable to soil development was found. Color and texture pattern changes were determined to be a result of the mixing of materials rather than developmental processes.

Illinois has an abundance of high quality soil materials to use for soil construction and row crop success on mine land has been as dependent upon the method by which soil horizons have been replaced as the quality of soil materials selected. Excellent corn and soybean yields have been achieved on low soil strength soils in high stress as well as low stress years. Soil horizon segregation and replacement in Illinois has generally shown a moderate positive yield response in most cases , however, the soil physical condition that is established during soil construction is clearly a more significant concern than whether or not materials from the natural soil horizons are replaced (Jansen and Dancer, 1981).

McSweeney and Jansen (1984) studied the soil structure patterns and rooting behavior of corn in constructed soils. On a site that received extensive grading of the subsoil, the subsoil was severely compacted and massive. Root penetration into these subsoils was extensively horizontal instead of the normal vertical direction. Cross sections of the roots were noticeably flattened and compressed. McSweeney described a "fritted" soil structure in areas where soil materials handled by a mining wheel-conveyor-spreader system where only minimal grading is necessary . Fritted structure was defined as an artificial soil structure consisting of rounded loose aggregates formed by rolling along the soil conveyor resulting in a low strength and a soil high in macropores. Although subject to compaction at the upper surface, the extensive void spaces between aggregates allow for excellent root penetration. Excellent corn and soybean yields have resulted from these low strength soils in high stress as well as low stress years. Rowcrop yields equal or higher than those obtained on nearby undisturbed soils were obtained in ten consecutive years studied (Dunker, et. al., 1992a). Topsoil, replaced with the soil spreader and graded by dozer at this southern Illinois site, has only infrequently produced any significant yield response. Both topsoil and non-topsoil treatments produced corn and soybean yields comparable to the undisturbed site.

Although the mining wheel-conveyor spreader system has proven successful in constructing productive soils after surface mining, it is a very inflexible system which can not be used at most mine sites. Evident options are to either develope a method by which excessively compacted soils can be ameliorated to a sgnificant depth or to develop other material handling options which will produce soils with good physical characteristics.

Corn and soybean response to mine soil construction with rear-dump trucks and scraper pans were studied from 1985-91 in southern Illinois (Hooks et al., 1992). Two truck-hauled treatments, one which limited truck traffic to the spoil base only, and one which allowed truck traffic on the rooting media as it was placed, were evaluated. A third treatment consisting of entirely scraper hauled rooting media was included. The rooting media was comprised primarily of the B horizon of the natural unmined soil and all treatments had 20 cm of topsoil replaced on the rooting media. Significant differences in soil strength, a measure of soil compaction, and rowcrop yields were observed among treatments over the seven year period. The truck without traffic treatment produced the highest corn yields of any of the mine soil treatments and were comparable to the undisturbed tract in every year of the study. Yields from this study using the rear dump truck system without surface traffic indicate restoration of productivity to premine levels. Any traffic on the surface of the rooting media can significantly reduce productivity, and may require some level of augmentation to improve the physical condition of the soil. Yields of the scraper built rooting media were below acceptable levels needed for bond release. A thorough augmentation of the physical condition of the soil profile will be required to restore productivity.

Thompson et al. (1987) used root length and root length densities to evaluate how bulk densities and soil strength values are predictors of root system performance. Because root restriction is generally the factor most important in limiting crop performance in mine soils, determining the suitability of soils for root system development could be a useful method of evaluating reclaimed soils. Soil strength was evaluated with the use of a constant rate recording cone penetrometer developed by Hooks and Jansen (1986). Results indicate that both penetrometer resistance and bulk density are useful predictors of root system performance in soils. They are especially useful in predicting root extension into deeper regions of the root zone. Penetrometer resistance and bulk density were highly correlated in the lower root zone, but poorly correlated nearer the soil surface.

Penetrometer data has proven useful for evaluating the soil strength effects of several reconstruction methods, of high traffic lanes on reclaimed areas and of tillage methods for alleviating compaction (Vance et al., 1992). Soil strength values decreased with decreasing traffic. Scraper soil material handling systems produced the highest soil strengths, soils from truck-haul systems were intermediate, and soils built by a wheel-conveyor-spreader system had the lowest soil strength. The relationship between soil strength levels measured with a recording cone penetrometer and six-year corn and soybean yields of four reclamation methods were evaluated. Reclamation treatments included the wheel-conveyor system, truck-hauled root media with and without surface traffic, and a scraper-hauled rooting media system. Penetrometer measurements have resulted in wide ranging values between reclamation treatments and corresponding wide ranging values in crop yield. Correlation of penetrometer resistance with crop yield has been significant within most years for both corn and soybeans. Reclamation treatments with the highest soil strength had the lowest yields, those with the lowest soil strength had the highest yields. Average soil strength over the 22-112 cm profile depth was highly correlated with six-year mean yields across reclamation treatments.

It appears that soil strength measurements with the deep profile penetrometer is a viable method for assessing long term yield potential of mined land when chemical and plant nutritional variables are not yield limiting factors. While yield variation among years is associated more closely to weather variables than soil factors, soil strength appears to be closely correlated to mean yields averaged over multiple years.

DEEP TILLAGE

The effect of using a deep soil loosener (Kaeble-Gmeinder TLG-12) on corn grown on wheel spoil was evaluated over a two year period at Norris Mine in western Illinois (Dunker et al., 1989). The TLG-12 has an effective tillage depth of approximately 75 cm and was successful in significantly lowering penetrometer resistance in the 23-46 cm and 46-68 cm segments when compared to the unripped wheel spoil treatments. Corn yield response to the TLG-12 was significant in both years (1985-86) although the magnitude of response was greater in 1985, a year of greater climatic stress. Significant differences for pollination dates, % barren stalks, shelling %, and soil moisture tension levels at certain depths were observed between the ripped and non-ripped treatments. Two year average corn yields for both topsoil/wheel spoil and wheel spoil without topsoil were comparable to corn yields from a nearby Sable soil while two year non-ripped mine soil yields were not.

In southern Illinois, the effects of the TLG-12 was evaluated on scraper placed rooting medium and 20 cm of scraper placed topsoil (Hooks et al., 1987). Corn and wheat were planted in 1985. Corn, soybeans, and grain sorghum were planted in 1986. The test plots, which totaled 25 hectares were located within three adjacent areas with a ripped and non-ripped block within each area. Yield results showed a significant positive response to the deep tillage treatment for all crops in both 1985 and 1986.

The effects of six deep tillage treatments ranging in depth from 20 to 120 cm were evaluated on a reclaimed mine soil over a four year period in southern Illinois (Dunker et al., 1992b). The mine soil consists of 20 cm of topsoil replaced over 106 cm of scraper-placed rooting media. The pre-tillage physical condition of this mine soil is described as compact and massive. A nearby tract of Cisne silt loam (Mollic Albaqualf) was used as an unmined comparison. Significant differences in corn and soybean yield, soil strength measured with a cone penetrometer, and net water extraction were observed among tillage treatments. Significant correlations between soil strength and rowcrop yields resulted in both years of the study. Yields comparable to the undisturbed Cisne soil were achieved on the deeper tillage treatments. Corn yield increased with increasing tillage depth within and across years. Post-tillage penetrometer data indicate that amelioration effects of tillage after initial application of tillage have remained over the duration of this four-year study. These deep tilled soils may be subject to recompaction, however, and management plans after tillage must include compaction avoidance techniques.

MANAGEMENT AND CROP SELECTION

Obtaining optimum row crop productivity on reconstructed mine soils requires the understanding of complex integrated soil, water, climatic, and genetic relationships. Crop varieties, plant populations, herbicides and fertilizer rates are management factors that are generally recognized as affecting crop yields. The effects of these management factors are compounded when row crops are grown on newly constructed mine soils, which may have wide ranging physical and chemical properties, making it difficult to project productivity success. Corn yields of current commercial hybrids display considerable year-to-year variation when grown on mined land. There have been significant yield differences among soil reconstruction treatments in most years for an individual hybrid, but the ranking of treatments has not been consistent from year to year.

Forty corn hybrids in 1984 and thirty-eight hybrids in 1985 were planted on two mine soils and an undisturbed tract at Norris mine in western Illinois to evaluate a wide range of genotypes on newly constructed mine soils (Dunker et al., 1988). The two mine soils consisted of one being 45 cm of topsoil replaced by scrapers over wheel spoil and one consisting of wheel spoil only. A nearby tract of Sable soil (Typic Haplaquoll) was used as the unmined comparison. Results from this study indicate that the potential to minimize the effects of stress exists through hybrid selection of adapted genotypes. Hybrids with the highest potential on unmined soils did not necessarily produce the higher yields on the disturbed soils. Weather variables were found to be more significantly associated with yield variation on the mine soils than on the Sable soil. Significant differences in pollination dates among soil treatments for a hybrid were observed in both 1984 and 1985. Hybrids on the Sable soil, in general, were the first to pollinate, followed by hybrids on the topsoil treatment, with hybrids on the wheel spoil being last to shed pollen.

Many of the physical problems in reclamation for rowcrop production have been identified and the assumption has been made that chemical amendments can be applied to alleviate perceived plant nutrition problems. However, soil analysis calibrated with crop yield and fertilizer responses on natural occurring soils may not be precisely applicable to reclaimed soils. It has been recognized that K uptake is affected by compaction on natural soils and it does not seem unreasonable that compaction during material handling and soil construction might affect K fertilizer response and K uptake on reclaimed land. Changes in organic matter, soil pH and microorganism populations may reduce or enhance levels of available essential elements in reconstructed soils.

The effects on corn leaf composition of six deep tillage treatments ranging in depth from 20 to 122 cm were evaluated on a reclaimed mine soil over a two year period in southern Illinois (Walker, et al., 1990). The mine soil consists of 20 cm of topsoil replaced over 106 cm of scraper-placed rooting media. A nearby tract of Cisne silt loam (Mollic Albaqualf) was used as an unmined comparison. In 1988, significant differences in corn leaf P, K, Mg, S, B, Fe, and Mn were observed. Nutrient levels were adequate for higher yields than those obtained. No significant correlation between soil test values and respective leaf concentrations occurred in 1988. In 1989, significant differences in corn leaf N, P, Ca, Mg, S, B, Mn, and Zn occurred due to tillage treatments. Only soil Mg and soil B (0-20 cm) were significantly correlated with their respective leaf composition in 1989. Although variability in leaf nutrients was affected by tillage treatments in both years of this study, leaf concentrations would not be considered deficient in most plant analysis sufficiency tables. In a companion study, response of corn grown on scraper placed rooting media to annual applications of selected rates and combinations of N, P, and K was measured at a mine site in southern Illinois (Walker, et al., 1992). Rates of N. P. and K ranged from 0-225 kg/ha, 0-90 kg/ha and 0-135 kg/ha, respectively. Results of this study indicated that although the chemical composition of the corn leaf in any particular year could be attributed to one or more fertility variables, that other factors such as moisture stress may have limited crop yield and response to fertilizer variables. Peck et al. (1969) and Walker et al. (1969, 1974) have determined relationships between plant composition and crop yields with various algebraic models for natural soils and will be used as the basis of model development for mined land.

In summary, results from the Illinois work shows that achieving mine land productivity is attainable if reclamation plans are designed to minimize compaction, use good quality soil materials and use high management levels (herbicides, fertility, adapted crop varieties) in rowcrop production. Deep tillage is an option which may be used to alleviate compaction which is unavoidable in the reclamation process.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

"RECLAIMING CROPLANDS IN MONTANA"

Bill F. Schwarzkoph[1]

ABSTRACT

Colstrip was founded in 1923 when Northern Pacific Railroad (NP) began mining coal to use as fuel for their locomotives. Mining continued until 1958, when diesel fuel replaced coal as locomotive power. In 1968 Montana Power Company (MPC) purchased the Colstrip coal properties in order to produce steam electrical power from coal. With strip mine laws looming in the near future, MPC regraded most of the old NP spoil banks. Most were reseeded to introduced grasses, mainly crested wheat grass (*Agropyron cristatum*). Some were planted to winter wheat (*Triticum aestivum*). Due to the semi-arid conditions of southeastern Montana and the lack of soil the wheat did very poorly. MPC formed Western Energy Company to resume the mining at the Rosebud mine. State reclamation laws initially did not allow cropland reclamation. It seemed unsavory to allow a mining company to mine through native prairie with intentions to convert it to wheat. During the 1970's every serious coal company in Montana developed grassland prairie reclamation. Cropland reclamation efforts were ignored. After federal laws were enacted, Montana law was changed to allow cropland reclamation through an"Alternate Reclamation Plan". Montana rules require that all mined land be reclaimed to it's natural state. All other efforts must go through the Alternate Reclamation Plan. In 1984 Western Energy Company began plans to reclaim croplands where croplands existed prior to mining. Thus far 210 acres of croplands have been reclaimed at the Rosebud Mine. Crops consist of wheat, oats (*Avena sativa*), and alfalfa (*Medicago sativa*). These agricultural fields are meeting pre-mine production and have been very beneficial to area wildlife species such as mule deer (*Odocoileus hemionus*), antelope (*Antilocopra americana*), and sharp-tailed grouse (*Tympanucus phasianellus*).

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[1] Western Energy Company Rosebud Mine Colstrip, MT 5932

INTRODUCTION

Surface mining for sub-bituminous coal began at Colstrip in 1923. The coal was used to fuel Northern Pacific Railroad locomotives. Mining lasted until 1955 and by that time railroads had switched from coal to diesel fuel to power their locomotives. the Colstrip coal mine sat idle until 1968 when Montana Power Company (MPC) purchased the properties, founded Western Energy Company (WECo), and began mining once again. This time the coal was used as fuel for electric steam generating power plants. The coal was used locally and also shipped out of state.

In the early 70's citizens demanded environmental safeguards. Mining from 1923 to 1955 left the land in destruction. Citizen's groups such as the Northern Plains Resource Council were instrumental in getting legislators to write reclamation regulations. Knowing in 1967 that reclamation regulations were just around the corner, MPC set about regrading some of the old spoils left from the 1923-1955 era. Much of the effort was simply dozing the ridges flat and rounding the edges. Seeding consisted of simple seed mixes of introduced grasses, usually crested wheatgrass (*Agropyron cristatum*), and a legume, usually yellow sweet clover (*Melilotus officinalis*) or alfalfa (*Medicago sativa*). Some sites were seeded to wheat (*Triticum aestivum*). In the semi-arid conditions of southeastern Montana and with the lack of any soil, the wheat did very poorly.

Montana's first reclamation laws were enacted in 1973. At that time, cropland reclamation was not allowed. In 1979 the federal government's Office of Surface Mining (OSM) developed regulations. To comply with the OSM, Montana Department of State Lands (DSL) changed their reclamation laws to meet federal regulations. The new state regulations allowed for cropland reclamation through a special section titled "Alternate Reclamation".

DISCUSSION

From 1967 through the 1970's most Montana coal companies were caught up in the rush to effectively establish proper reclamation methods to obtain grassland or rangeland conditions similar to undisturbed rangeland. During this period seed mixtures consisted of introduced and native grasses. By the start of the 80's, most grassland reclamation consisted of all native grass seed mixes. Researchers and reclamationists were changing methods each year to keep up with the best technology currently available (BTCA) in the new business of reclamation.

In 1981 WECo was in the process of permitting a portion of Area B, (Sections 4, 9, & 10) and went through the proper data gathering, hearings and permitting processes. In the Environmental Impact Statement (EIS), the Montana Department of Agriculture sent a letter of concern. It stated that "the department was concerned with the loss of agricultural land in the Area B (4, 9 & 10) permit and DSL should require WECo to reclaim croplands (EIS, 80)."

That statement was the first "push" by anyone to reclaim croplands in Montana. Ironically, at that same time WECo was mining through 716 acres of cropland in Area A, (WECo, 1988). However, it was all being reclaimed as grassland and/or rangeland.

With that initial nudge, WECo evaluated the advantages of post-mine croplands in the Colstrip vicinity. Pre-mine wildlife use indicated that mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*) and sharp-tailed grouse (*Tympanuchus phasianellus*) all utilized croplands during specific periods of the year (Table 1.). Mule deer and antelope used alfalfa fields in the fall and winter wheat and oats (*Avena fatua*) in the spring. Sharp-tailed grouse used the wheat and oat fields in spring and fall. Collectively the agriculture fields were an important component of the pre-mine habitats. Wildlife were definitely benefiting from the diversification that croplands added to the pre-mine habitats.

TABLE 1. PRE-MINE UTILIZATION OF CROPLANDS BY THREE GAME SPECIES

GAME SPECIES	PERCENT OF OBSERVATIONS IN CROPLANDS[1]				
	Spring	Summer	Fall	Winter	Total
Mule Deer	11	1	9	-	7
Pronghorned Antelope	13	8	16	-	12
Sharp tailed Grouse	33	-	17	-	17

[1] ECON 1979

Croplands would also benefit the local farmer-rancher. Croplands constituted a cash crop and also provided winter feed for their cattle. Not all ranchers have wet bottomlands for winter hay. In these cases hayland in the uplands are an important segment of their ranch operation.

Another good reason for cropland reclamation would be the potential ease of obtaining future bond release. It is much simpler to compare post-mine cropland production to pre-mine production or to reference fields than the extensive, expensive studies of grassland reclamation vs. reference areas which require statistical analysis of cover, diversity and production of grasses (warm season and cool season) forbs and shrubs. Cropland bond release should be a much simpler process. This savings in time and work definitely is worth the effort to reclaim to croplands especially where pre-mine croplands existed previously.

Another example of simple economics is that cropland seed is cheaper than a native grass/forb mix. Also, bond period management costs are nil since a local area farmer does the seeding tilling, fallowing, and harvesting.

WECo found no negative points regarding cropland reclamation, unless poor soils are used. WECo does not intend to convert grasslands to cropland. Their interest is only to reclaim former cropland acres.

Lastly, It did not seem to make sense to reclaim "former" croplands to native rangeland (with all the uncertainties of bond release) when it is well known that the local farmer-rancher will plow the reclaimed grassland after future bond release.

METHODS

WECo's plan for cropland is to initially plant cereal grains for one or two years to aid in preparing and smoothing the fields for farm equipment use. Then alfalfa is seeded either alone or with a nurse crop of oats or spring wheat. The alfalfa is left for five to six years to enhance soil fertility through nitrogen fixation. After six years, some of the alfalfa fields may be plowed and rotated to cereal grains or left in alflafa until bond relase. All farming practices, such as tilling, planting, and harvesting is done by a local farmer.

Thus far, 210 acres of cropland have been reclaimed through the alternate reclamation plan at the Rosebud mine. Crops have consisted of cereal grains and alfalfa. Cereal grains have consisted of spring and winter wheat, barley (*Hordeum vulgare*) and oats.

RESULTS

Wildlife use of the post-mine croplands have equalled or exceeded use of pre-mine croplands, based on casual ground and aerial observations. Thus far observations of game species on the mine have only been recorded as using "reclamation". Reclamation areas are now large and diverse enough, that more emphasis is needed on segregating wildlife use of the various types of reclamation. Future observations of game species will be seperated as to cropland reclamation or varous types of rangeland reclamation.

The Area A cropland fields were started in 1985. Three new fields were seeded to barley and winter wheat. The barley yielded 12.2 bushels/acres and the winter wheat yielded 27.9 bushels/acre, table 2. In the spring of 1986 these fields were seeded to alfalfa without a grain nurse crop, so no production occurred.

TABLE 2. PRODUCTION OF POST-MINE CROPLANDS FOR THE PERIOD OF 1985-1992

Year	AREA A			AREA C			
	Spring Wheat	Barley	Alfalfa	Spring Wheat	Winter Wheat	Oats	Alfalfa
1992			0.72[3,4]	12.5[1]	47.2[2]	-	1.58[4]
1991			1.86	14.8[1]	-	-	0.65
1990			1.13	11.1[1]	-	-	-
1989			0.90[3]	-	27.0[1]	37.0	-
1988			0				
1987			0.58				
1986			-				
1985	27.9	12.2	-				
Ave.	27.9	12.2	0.89	12.8	37.1	37.0	1.12

[1] These figures used to calculate average postmine wheat production of 18.7 bu/ac.

[2] Production of 47.2 bu/ac. was left out of averages because it was fertilized

[3] Cutworm damage

[4] Fertilized

Alfalfa production for the six year period of 1987 to 1992 ranged from a low of zero production during the drought year of 1988 to a high of 1.86 tons/acres in 1991, table 2. Adjacent croplands on undisturbed lands also yielded zero production in 1988. Average production during that period was 0.89 tons/acre, which compared favorable to a ten year (1971-1980) premine average of 0.77 tons/acre for dryland alfalfa, table 3.

TABLE 3. PRODUCTION OF POST-MINE CROPLANDS VS. PRE-MINE

CROP	PRE-MINE	AREA A	AREA C
Wheat	26.0[1](13.0)[2]	27.9	16.4[3]
Alfalfa	0.77	0.89	1.12[4]

[1] Pre-mine average based on fallow/Rotation cropping.

[2] Pre-mine average based on continuous cropping

[3] Average Spring Wheat and Winter Wheat.

[4] 92 Fertilized Production used.

A study through the Montana State University Reclamation Research Unit, sponsored by WECo, indicated that production from a reclaimed alfalfa field in Area A equalled production of a similar off-mine alfalfa field. This study indicated that the potential for dryland alfalfa production on mine soil was comparable to undisturbed sites in the same area, (Postle 85).

The Area C cropland fields were started in 1989. Two fields were seeded, one to winter wheat and one to oats. The production of these fields were 27 and 37 bushel/acre, respectively, table 2. In 1990 these fields were seeded to alfalfa along with a nurse crop of spring wheat. The wheat yielded 11.1 bushels/acre. In 1991 four more fields were added and these were seeded to spring wheat as a nurse crop and alfalfa. 1991 wheat production was 14.8 bushels/acre overall and the alfalfa produced 0.65 tons/acre, table 2. In the fall of 1991 an additional field was added and seeded to winter wheat. In the spring of 1992 another field adjacent to the winter wheat field was added and it was seeded to spring wheat. 1992 production for spring wheat and winter wheat was 12.5 and 47.2 bushels/acre respectively, table 2. Alfalfa production from six fields in 1992 averaged 1.58 ton/acre.

The fallow/rotation system for wheat has not been used to date. Rather, continuous cropping has been used. Average post-mine wheat production of 18.7 bushels/acre annually compares favorable to a seventeen year (1964-1980) pre-mine average of 26.0 bushels/acre, because the pre-mine production was taken from the fallow/rotation system. On an annual basis considering fallow acres also, pre-mine production was actually only 13 bushels/acre, table 3.

Field sizes for eleven fields in areas A and C range from 10 to 51 acres in size with an average of 19 acres each. Cut worm infestations lowered alfalfa productions in area A in 1989 and 1992. Aerial spraying with "Ambush" was used on the Area A fields in 1992.

No fertilization was used except in 1992. Fertilizer (NPK of 11-53-0) was left over in the warehouse from pre-1984 regular use for grassland establishment and was only used to get rid of it and clean out the warehouse. It was placed on all the alfalfa fields at a rate of 75#/acre and the Area C winter wheat field at a rate of 100#/acre. The 1992 winter wheat production was not used to calculate the average wheat production of 18.7 bushels/acre for the Area A and C together or the 16.4 bushels/acre for the Area C alone.

In summary, cropland reclamation appears to be meeting production standards adequately and provides another important habitat component for wildlife. At bond release time, local farmer/ranchers will have in place good productive croplands to supplement their ranching business.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

APPLICATION OF RANDOM SAMPLING METHODOLOGY AT ABSALOKA MINE; HARDIN, MONTANA

D.D. Myran, K.L. Scow, K.J. Wendtland

ABSTRACT

Preparation for an amendment application provided an opportunity for Westmoreland to revise vegetation data collection methods. Vegetation data collection in the proposed amendment area and existing reference area was conducted during 1991 using a random plot methodology, which is required for reclamation bond release by 1990 revisions to the Administrative Rules of Montana. Under a monitoring plan revision approved by the regulatory agencies, several revegetated areas were also sampled in 1991 using the same random sampling methods.

Cover, production and woody plant density data from predominantly graminoid community types in the amendment and reference areas were collected and analyzed separately and were also combined for comparison with graminoid dominated revegetated areas.

Random sampling of revegetated areas was expanded in 1992 to further evaluate the applicability of the methodology to revegetated stands, including tree and shrub plantings.

Comparisons of data collected with historic methodology and the random plot procedure indicate that cover and production estimates are similar.

Adopting this random sampling method for revegetation monitoring will have several positive consequences:

1. The design is well suited to statistical comparisons and would require only intensification of sampling to meet final bond release requirements.

2. The same methodology can be used on all reclaimed areas.

3. This approach allows direct comparison between revegetation data and the most recent pre-mining and reference area data.

4. A random design provides better representation of the heterogeneous nature of reclaimed and native areas.

5. Data collection on a larger spatial scale will better define post-mining land use capabilities.

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APPLICATION OF RANDOM SAMPLING METHODOLOGY AT ABSALOKA MINE; HARDIN, MONTANA

INTRODUCTION

Westmoreland Resources, Inc. owns and operates the Absaloka Mine, a surface coal mine in northeastern Big Horn County, Montana. One aspect of our mining permit is monitoring of revegetation success on reclaimed areas as required by Montana law.

Quantitative revegetation monitoring at Absaloka Mine began in 1979. Monitoring activities were concentrated on permanent transects located in individual reclaimed stands. First and second growing season reclaimed stands were sampled to evaluate success of native species establishment by counting individual plants by species in each of twenty 2 x 5 decimeter plots along a 300-foot line. Percent canopy cover by morphological class was estimated by a modified Daubenmire method.

Established grasslands were sampled by estimating canopy cover by morphological class and species in each of twenty 2 x 5 decimeter plots placed along a 300-foot transect using the same Daubenmire cover class system.

In addition, above-ground production was determined by clipping vegetation in five 0.5 square meter plots placed near each transect at 60-foot intervals. Samples were separated by morphological class and origin, air-dried and weighed.

Obviously, this approach would soon result in a large number of transects. In order to maximize annual sampling effort as more stands were reclaimed, a rotating sampling schedule was implemented in 1980. Additional monitoring activities included occasional seedling counts in reclaimed tree and shrub stands and annual utilization estimates on grazed reclamation.

An internal review of our revegetation monitoring program identified five main problem areas:

1. Annual sampling requirements were approaching an unmanageable level.

2. The use of permanent transects excluded many acres of reclamation from quantitative evaluation.

3. Different methodologies used for establishment determination, trend monitoring and, tree and shrub reclamation reduced the comparability of data.

4. Methods in use lacked comparability to final bond release sampling methods required by the 1990 revision of the Administrative Rules of Montana.

5. Sampling of individual stands had limited relationship to management objectives of the post-mining land use plan.

Preparation of an amendment application provided an opportunity to revise the existing monitoring plan. Vegetation data collection in the proposed amendment area and existing reference area were conducted during 1991 using a random sampling methodology.

Operating under an addendum to the sampling plan approved by the regulatory agencies, groups of similar or complementary revegetated stands, which are referred to as management units, were sampled using the same random sampling methodology (cover, production, diversity and woody plant density) used to sample native vegetation. Random sampling of revegetated areas was expanded in 1992 to further evaluate the applicability of the methodology to revegetated stands (Table 1). Preliminary results indicate that defensible comparisons can be made for bond release purposes.

METHODS

Sample locations were selected by a random procedure in the office. A recent aerial photograph was gridded at a spacing of 100 feet to select sample sites using a random numbers approach. Sample locations were found in the field using the aerial photo, landmarks, a compass for bearing and an established pace for distance. Sample size varied by native vegetation community, depending on community variability and aerial extent. Sample size was based on statistical adequacy formulas (Wyoming DEQ 1989) and professional judgment . Sample size varied among management units based on aerial extent, number of stands in a unit and achievement of sample adequacy.

Plot sizes at each sample site varied according to sample parameter:

1) estimation of canopy cover was made on a 0.01 acre circular plot centered on each randomly selected point;
2) annual production was harvested in a $0.5m^2$ rectangular plot centered on each random point;
3) species diversity was evaluated by recording all vascular plant species present in a 0.1 acre circular plot centered on each random point;
4) tree density was estimated by recording all individuals by species and class in the 0.1 acre plot; shrub density was estimated by recording all individuals by species and age class in six 0.001 acre circular plots distributed randomly within the 0.1 acre plot.

Canopy Cover

In each 0.01 acre plot, an ocular estimate was made of percent cover for bare ground, rock, litter, lichens, moss, and each vascular plant species. Absolute values (percent) were also recorded for total vascular plant cover and for morphological class categories (tree, shrub, subshrub, perennial and annual graminoid, and perennial and annual/biennial forb). Incidental species (all vascular plant species which occurred within the 0.1 acre plots) were recorded to allow comparisons of diversity.

Production

Range cages were established in grazed areas. In each 0.5 m2 quadrat, annual aboveground production was clipped and separated for the following herbaceous classes: perennial grasses and sedges, annual grasses, perennial forbs, and annual/biennial forbs. These classes were further separated as to origin (native vs. introduced) and, for perennial graminoids, seasonality (cool-season vs. warm-season species). Decreaser and major increaser grasses were separated by species. Current annual growth of subshrubs and shrubs was estimated by clipping an annual leader of each species, then counting remaining leaders within a vertical projection of the quadrat to be used as a multiplier. In the laboratory, all production samples were oven-dried at 70 C for 48-72 hours until constant weight was achieved, and weighed to the nearest 0.01 gram.

Tree and Shrub Density

Tree density was recorded on 0.1 acre plots. Trees were counted in each plot by species for the following diameter-at-breast-height (dbh) classes: less than 1-inch dbh and 1 to 4-inch dbh. Data were recorded separately for live and dead trees.

Shrub densities were determined for each species by counting the number of individuals rooted within six 0.001 acre plots distributed randomly within each 0.1 acre plot. Individuals were recorded by age class as seedling, immature, mature, decadent or dead.

DISCUSSION & CONCLUSION

Adopting this random sampling method for revegetation monitoring has several positive consequences.

1. The design is well suited to statistical comparisons and would require only intensification of sampling to meet final bond release requirements.
2. The same methodology can be used on all reclaimed stands.
3. This approach allows a direct comparison between revegetation data and the most recent pre-mining and reference area data.
4. A random design provides better representation of the heterogeneous nature of reclaimed areas.
5. Data collection on a management unit basis will better define post-mining land use capabilities.

Random sampling tends to reduce sample intensity while increasing sample frequency. This contrasts with the historical, transect method which sampled more intensively and less frequently. In theory frequent sampling should be more sensitive to the diverse precipitation patterns of the Northern Great Plains and the resultant effect on vegetation and thus, more accurately measure successional trends in reclaimed areas.

Utilization of limited sample numbers requires use of an established criterion for stratification to increase the precision and power of the sampling design. Several options for stratifying reclaimed areas exist. Stratification based on seeding date, seed mix or species composition have been considered however, a stratification criterion has not yet been selected. Evaluation of sample intensity and frequency and stratification procedures will continue as the sampling plan develops.

When these points have been adequately addressed, Westmoreland will have an efficient and effective vegetation sampling program in place for monitoring and bond release purposes.

Table 1. Summary of canopy cover and production for three Management Units, Westmoreland Reclamation, 1991 – 1992.

	CANOPY COVER (PERCENT)								PRODUCTION (GRAMS/SQUARE METER)							
	MANAGEMENT UNIT 1		MANAGEMENT UNIT 2		MANAGEMENT UNIT 3		RECLAMATION MEAN		MANAGEMENT UNIT 1		MANAGEMENT UNIT 2		MANAGEMENT UNIT 3		RECLAMATION MEAN	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
	n=23	n=26	n=18	n=25	n=12	n=18	n=53	n=69	n=23	n=26	n=18	n=25	n=12	n=18	n=53	n=69
VEGETATION STRUCTURE (nonstratified cover and production)																
Perennial Graminoids	49	45	38	28	27	24	41	33	161	140	105	82	69	56	121	97
Annual Graminoids	5	9	3	17	23	15	8	14	14	24	9	40	53	51	21	37
Perennial Forbs	3	5	6	13	7	14	5	10	7	7	16	39	9	34	11	26
Annual/Biennial Forbs	3	6	6	27	9	13	5	15	17	11	14	87	20	36	17	45
Subshrubs	T	T	T	T	T	1	T	T	T	T	–	T	–	T	T	T
Shrubs	T	T	T	T	T	T	T	T	1	–	T	T	–	–	T	T
Trees	–	1	–	T	–	T	–	T	NC	NC	NC	NC	NC	NC	NC	NC
TOTAL	55	59	50	67	59	57	54	61	201	183	144	248	151	177	170	205
VEGETATION CLASS (stratified cover and production)																
Native Perennial Graminoids (Cool)	17	23	28	17	19	19	21	20	50	76	66	52	47	49	55	60
Native Perennial Graminoids (Warm)	T	T	2	4	T	1	1	2	T	T	8	10	6	2	4	4
Introduced Perennial Graminoids	34	25	12	8	8	5	21	14	111	64	32	20	16	6	63	33
Native Annual Graminoids	–	–	–	T	–	T	–	T	–	–	–	T	–	T	–	T
Introduced Annual Graminoids	5	9	3	18	23	16	8	14	14	24	9	40	53	51	21	37
Native Perennial Forbs	1	3	5	10	4	10	3	8	4	5	15	27	7	25	9	18
Introduced Perennial Forbs	2	2	2	4	3	5	2	3	3	2	1	12	2	9	2	7
Native Annual/Biennial Forbs	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
Introduced Annual/Biennial Forbs	4	6	6	29	9	14	6	17	17	11	14	87	20	35	17	45
Subshrubs	T	T	T	T	T	1	T	T	T	T	–	T	–	T	T	T
Shrubs	T	T	T	T	T	T	T	T	1	–	T	T	–	–	T	T
Trees	–	1	–	T	–	T	–	T	NC	NC	NC	NC	NC	NC	NC	NC
TOTAL	64	70	58	92	68	72	63	78	201	183	144	248	151	177	170	205

NC = Not Collected

T (Trace) = a value less than 1

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1993

LONG-TERM SUCCESSIONAL STUDIES ON DRASTICALLY DISTURBED LANDS

Daylan W. Figgs[1]

ABSTRACT

The regulations that govern surface coal mining require postmining vegetation that is diverse, effective, permanent, compatible with surrounding vegetation communities, and capable of self-regeneration and succession. While these requirements seem obtainable, it is unclear if current reclamation techniques can achieve these desired properties for areas reclaimed to native plant communities. Current reclamation practices call for uniformly grading the landscape, overlaying this with a soil of uniform thickness, followed by incorporating a large quantity of a highly diverse seed mix. This creates a landscape of reduced topoedaphic diversity and an initial vegetation density and diversity higher than the soil may be capable of sustaining. As a result, a common trend appearing in the arid and semi-arid reclaimed native plant communities is one of decreasing plant diversity over time. This trend seems to increase in intensity as the quality of minesoil reconstruction decreases. While this affects only the diversity requirements, diversity (alpha, beta, and mosaic) may be the most important measurable component of native plant communities. Failure to establish a diverse plant community makes it unlikely the other criteria will be met. Long-term successional studies are needed to determine the relationship between plant community composition and soil nutrient/moisture availability.

Key Words: plant community, succession, diversity, long term studies

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EVALUATION OF A TOPSOIL DEPTH STUDY WEDGE PLOT IN NORTHWESTERN NEW MEXICO

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ABSTRACT

In 1980, a topsoil depth study was established, in the San Juan Basin of Northwestern New Mexico, to evaluate the effects of differentiating depths of topsoil on revegetation success. The establishment of a long term study area to evaluate success and effects of topsoil depth and community succession is critical in arid climates. The development of the "wedge plot" was accomplished by placing topsoil in a wedge having dimensions of 42 meters north to south and 18 meters east to west. Topsoil depths ranged from 0 cm topsoil at the southern end to 120 cm topsoil at the northern end. Baseline data on soils and spoils was not established or has been misplaced. Recent spoil analysis indicate that the material used has a clay loam texture with sodium absorption ratios averaging 31.9. Topsoil was retrieved from a nearby source which has a sand texture. After initial seeding, the wedge plot was fenced to exclude all grazing animals. Irrigation was conducted for the first two growing seasons to ensure establishment. The wedge is located in a 6 to 8 inch precipitation zone.

Vegetation composition, based on a seed mix of native species, shows a variable stand, dependent on soil depth after being in place twelve years. Variability of species is a response to soil texture, soil/spoil chemical composition and soil depth. Evaluation indicates that, as top dressing depth increases, a stand of dominant grasses gradually changes to a grass/forb followed by a grass/dense shrub community. Total cover values range from 1.11 percent with 5 cm top dressing, gradually increasing to 4.1 percent with 23 cm top dressing, then decreasing in cover as top dressing depth increases. Species composition and cover varies with depth of topsoil at the wedge plot in Northwest New Mexico.

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INTRODUCTION

Concerns about biological diversity and multiple use have directed attention away from the establishment of monocultures to that of more complex synthetic communities that are representative of natural communities (Call and Roundy 1991). To evaluate local arid conditions and reveal some of the unknown questions of arid climates, a wedge plot was established in 1980, by Sunbelt Mining Co. Inc. It is located approximately 33 miles south of Farmington, New Mexico in the San Juan Basin. Local elevation is approximately 1800 meters (5900 ft.). Placement of the wedge is on graded, light olive gray to greenish gray, silty and sandy, mudstone shale (i.e. spoil) (Scott et.al. 1979) . Above the graded spoil eolian, sandy, soil from nearby dunes was placed to a level fill, creating a wedge formation with no top dressing on the southern end increasing to 120 cm of top dressing on the northern end.

The complete plot size is 42 meters north to south and 18 meters east to west. Within the plot an evaluation area was marked off. The evaluation plot size was 36 meters north to south and 10 meters east to west, with an approximately 2 meter perimeter boundary to help eliminate edge effect. The plot was seeded, mulched and irrigated for two seasons (personal communication, Tim Ramsey, 1992) to establish vegetation in the 15 to 20 cm (6 to 8 in.) annual precipitation zone. After being in place with only minor disturbance caused by small mammals and infrequent foot traffic, the plot was evaluated for perennial and annual cover and common soil analysis. The objective of this survey is to evaluate the effects spoil material, depth of topsoil and species have on the revegetated community after 12 years.

EVALUATION METHODS

VEGETATION

To acquire data on cover, diversity and density of plant life forms, permanent, non-random transects were established. Each transect was placed parallel with the depth of topsoil at 2 meter intervals to evaluate vegetation at specific top dressing depths. Transects were numbered alternately, starting with numbers 1, 3, 5 etc. up to transect number 35, then one additional transect was placed at the end of the evaluation plot, number 36, for a total of 19 transects. Spacing and numbering was established to allow additional transects to be incorporated at a later date, if needed. At each transect location the depth of topsoil was measured and recorded. Foliar cover and diversity data was taken using the line intercept method (Pieper, 1978) along a 10 meter tape. All plant species were identified and recorded as they transect the intercept line. Basal cover data (Pieper, 1978) was collected along each transect and was recorded where a grass species or other species transect the intercept line at each decimeter interval. Production of individual transects was not performed as not to add significant disturbance to the plot, for further study. Sampling was conducted in a manner to minimize disturbance.

SOIL & SPOIL

Soil and spoil sampling was conducted in a manner that would give position specific information on undisturbed shale, disturbed shale, graded spoil, native top dressing and replaced top dressing. Soil and spoil sampling was evaluated at the soil-spoil interface within the wedge plot. A hand auger for sandy soils was used for sampling. A total of 7 top dressing, 2 native soil and 12 shale and spoil samples were taken and analyzed. Top dressing analysis consisted of: Saturated paste pH, Electrical Conductivity (E.C.), Calcium (Ca), Magnesium (Mg), Sodium (Na), Sodium Absorption Ratio (S.A.R.), and Textural composition (Am.Society of Agronomy, Inc. 1982). An additional 2 samples were analyzed for nitrate nitrogen (NO_3), phosphate phosphrous (P_2O_5) and dissolved potassium.

Shale and spoil samples were analyzed for: Saturated paste pH, Electrical Conductivity (E.C.), Calcium (Ca), Magnesium (Mg), Sodium (Na), Sodium Absorption Ratio (S.A.R.), and Textural composition (Am.Society of Agronomy, Inc. 1982). Five of the 12 spoil samples were analyzed for Selenium. Hot water extractable and total perchloric digest methods were used for Selenium analysis. Samples for both spoil and top dressing were taken from the center of the evaluation plot at the 30 cm (12"), 45 cm (18"), 63 cm (25"), 74 cm (29") and 110 cm (43") top dressing depth locations. Additional sampling included graded spoil and undisturbed shale from local areas for analytical comparison to spoil material.

RESULTS & DISCUSSION

VEGETATION

Data from 19 transects had variation in species composition and cover. Foliar cover values ranged from 1.11 % with three species present, up to 4.1% cover with nine species present. Mean cover value was 2.68% with a sample standard deviation of 0.83. Fourteen of the 19 transects (74%) had cover values within one standard deviation of the mean. Top dressing depth of 2.5 cm (1") and 5.0 cm (2") had 1.3 % and 1.11 % cover respectively and were more than one standard deviation below the mean. Transects having top dressing depths of 18 cm (7"), 23 cm (9") and 46 cm (18") had cover values of 4.08%, 4.1 % and 3.81 % respectively, and were more than one standard deviation above the mean.

Dominant grass species include Alkali sacaton (*Sporobolus airoides* (Torr.(Torr.), (Hitchcock, 1950) Giant dropseed (*Sporobolus giganteus* (Nash.), and Blue grama (*Bouteloua gracilis* (H.B.K) Lag.ex Steud.). Alkali sacaton is present throughout the various top dressing depths, but most dominant in soils less than 46 cm (18"). Giant dropseed becomes established at 53 cm (21") through 110 cm (43"), the deepest top dressing. Blue grama is dominant in the 10 cm (4") to 30 cm (12") top dressing depth then becomes sparse at greater or shallower depths. Table 1 details the species and cover values at each transect.

TABLE 1. PERCENT COVER BY SPECIES

	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	36	ALL
AGSM								0.1	0.02							0.02				0.14
ATCA										0.3	0.32			0.45	0.38		0.33			1.78
ATPO	0.18	0.9																		0.27
BOGR				0.28	0.37	1.41	1.05	0.42	0.47	0.3	0.09		0.21		0.06	0.09	0.09			4.84
BRJA									0.01											0.01
BRTE			0.01																	0.01
CEsp	0.02						0.01		0.03	0.02										0.08
FEOC						0.04	0.04	0.07	0.1	0.39	0.45	0.7	0.72	0.05	0.13	0.37	0.04	0.01		3.11
FORB								0.03				0.07						0.08		0.18
GUSA							0.12													0.12
HIJA					0.09	0.75	0.28	0.13	0.43	0.37	0.27				0.1					2.42
LITT†	0.08	0.28	0.01	0.18	0.17	0.2	0.07	0.2	0.09	0.37	0.09	0.68	2.47	3.11	2.26	3.13	2.24	1.9	1.63	19.14
MEOF				0.04	0.04															0.08
ORHY									0.07		0.94		0.54		0.05	0.05	0.36	0.23	0.5	2.74
PLPA								0.1	0.14	0.09	0.03									0.36
RUVE										0.27			0.2	0.23	0.46	1.23	1.12	0.55	0.7	4.76
SAKA															0.02					0.02
SPAI	1 1	1.02	2.06	3.01	2.46	1.1	2.58	3.2	1.79	1.5	1.71	0.3	0.01			0.2	0.31			22.35
SPCO								0.05										0.5		0.55
SPCR									0.02			0.09			0.04	0.01		0.11	0.57	0.84
SPGI												0.91	0.82	1.57	1.07	0.7	0.26	0.55	0.49	6.37
ALL	1.3	1.11	2.07	3.33	2.96	3.3	4.08	4.1	3.08	3.24	3.81	2.07	2.5	2.3	2.31	2.67	2.51	2.03	2.26	51.03

† = litter cover not included in totals.

AGSM	Agropyron smithii	MEOF	Melilotus officinalis	PLPA	Plantago patagonica
ATCA	Atriplex canescens	CEsp.	Cerastium sp.	RUVE	Rumex venosus
ATPO	Atriplex powellii	FEOC	Festuca octoflora	SPAI	Sporobolus airoides
BOGR	Bouteloua gracilis	GUSA	Gutierrezia sarothrae	SPCO	Sphaeralcea coccinea
BRJA	Bromus japonicus	HIJA	Hilaria jamesii	SPCR	Sporobolus cryptandrus
BRTE	Bromus tectorum	ORHY	Oryzopsis hymenoides	SPGI	Sporobolus giganteus

The greatest change in cover values was the litter component. Litter values ranged from 0.01 % in transect 5 (7.5 cm or 3" top dressing) to 3.13 % in transect 31 (84 cm or 33" top dressing). Litter increased as top dressing increased due to the increased density of Fourwing saltbush (*Atriplex* *canescens* (Pursh) Nutt). Litter values were 0.37 % or less in top dressing up to 46 cm (18") then increased to a maximum of 3.13 % at top dressing depths of 53 cm (21") or greater in top dressing depth.

Basal cover evaluations found that 5 dominant species had become established on the wedge plot. Each significant species had a dominant position in the revegetated community, as identified before. Alkali sacaton and Blue grama were the two dominant grasses found in 17 and 13 of the 19 transects respectively. Secondary grasses included Sand dropseed (*Sporobolus cryptandrus* (Torr.) (A.Gray.), Giant dropseed (*Sporobolus giganteus*(Nash.), Galleta (*Hilaria jamesii* (Torr.) Benth.) occurring in 6, 7 and 7 of the 19 transects respectively. Other species rarely appeared. Table 2 summarizes results for basal hits along the 19 transects.

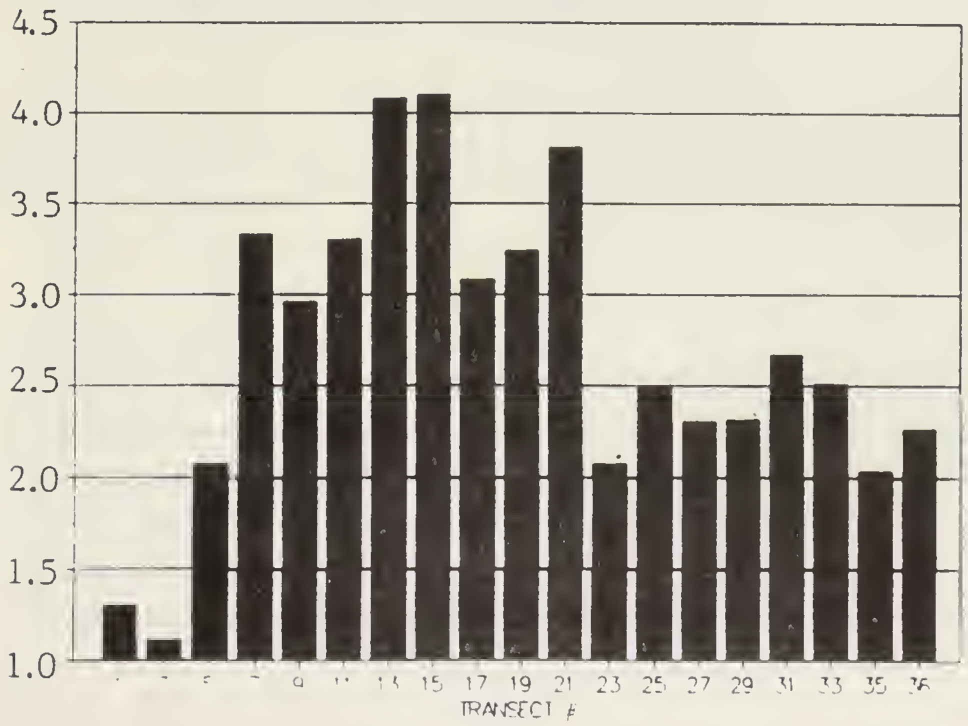
TABLE 2. NUMBER OF BASAL HITS ALONG 10 METER TRANSECTS.

	TRANSECT #																		
SPECIES	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	36
SPAI	5	4	8	12	13	9	14	10	10	5	7	4	4	4		1	2	1	
BOGR				2	7	12	6	2	1	3	1		1	1	1	2	1		
SPCR									1		1	1	1	1					2
SPGI												2	2	1	3	2		1	1
HIJA					1	1	1	3	1	3	2								
OTHER							1†	1‡			1§								

† ORHY ‡AGSM §GUSA

As soil depth increases, within the wedge plot, species composition changes. Between the 10 cm (7") and 45 cm (18") average cover was 3.48 %. Due to the droughty nature of the sandy textured top dressing, water holding capacity and inherent low fertility, deeper depths of top dressing did not contribute to improving diversity or cover. Within top dressing depths greater than 53 cm (21") cover decreased to an average of 2.33 %, a 33 % decrease in cover compared to areas with 10 to 45 cm of top dressing. The most diverse, highest foliar cover and basal cover values were transects that had top dressing depths of 18 cm (7") to 46 cm (18"). Figure 1 illustrates the foliar cover values at each transect.

FIGURE 1. PERCENT COVER USING LINE INTERCEPT METHOD.



SOIL AND SPOIL

Soil and spoil sampling was primarily evaluated at the soil-spoil interface. This was done to determine the chemical and physical conditions in which plants are forced to adapt for succession. Grasses represented the dominant seeded plant life-form on the topsoiled sites. This was the result of (1) greater seeding rates; (2) greater ability of grasses to germinate and compete; and (3) cultural techniques that favored grass establishment and survival (Francis et. al. 1991).

Spoil and disturbed shale samples have clay (2), clay loam (7), and loam (1) textures with electrical conductivity ranging from 1.33 to 9.8. SAR values for the same samples ranged from 20.3 to 38.7, within the same sample core at differing depths. Table 3 details the soil and spoil analysis.

TABLE 3. WEDGE PLOT SOIL & SPOIL ANALYSIS

SITE #	DEPTH cm	DEPTH in	pH	EC mmhos/cm	Ca meq/l	Mg meq/l	Na meq/l	SAR	SAND %	SILT %	CLAY %	TEXT	Se ext. hot H_2O	Se total per-chloric digest	NO_3 ppm	P_2O_5 ppm	K ppm
1 soil	23-30	9-12	8.4	0.74	0.64	0.18	8.07	12.6	90.4	5.1	4.5	SAND					
1 spoil	30-38	12-15	8.6	1.83	0.94	0.25	20.4	26.4	37.6	25.1	37.3	CL/L					
2 soil	0-30	0-12	8	0.62	3.01	0 57	1.76	1.32	90.4	6	3.6	SAND					
2A soil	30-38	12-15	8.1	0.33	0.95	0.21	3.11	4.08	92.2	3.3	4.5	SAND					
2B soil	38-46	15-18	8.5	0.33	2.93	0 67	4.1	3.06	94	2.4	3.6	SAND					
2C spoil	46-50	18-20	8.5	1.33	0.99	0.27	16.1	20.3	30.4	42.3	27.3	CL/L					
2D spoil	50-58	20-23	8.2	4.58	3.96	0.91	59	38.7	28.6	45.1	26.4	LOAM					
2E spoil	58 86	23-34	7 8	8.58	15.7	3.38	99.8	32.3	21.3	50.5	28.2	CL/L					
3 soil	43-64	17-25	8.4	0.61	1.07	0.2	6.51	8.17	90.4	5.1	4.5	SAND					
3 spoil	64-79	25-31	8 4	3.13	1.98	0.53	36.7	32.8	29.5	38.7	31.8	CL/L					
4 soil	61-74	24-29	8.2	0.54	1.5	0.32	4.81	5.04	88.5	6	5.5	SAND					
4 spoil	74-89	29-35	8.3	3.8	3.82	0.77	45.1	29.8	31.3	31.4	37.3	CL/L					
5 soil	81-110	32-43	8.2	2.55	2.95	0.52	9.99	7.58	90 4	6	3.6	SAND					
5 spoil	110-124	43-49	8.1	7.19	14.4	3.24	80.8	27.2	32.2	34.2	33.6	CL/L					
DIST SHALE	0-50	0-20	8.2	5.2	7.9	1.2	62	29.1	44	42	14	CLAY	0.13	<.15			
DIST SHALE	24-50	10-20	7.9	9.8	19.1	3.9	120	34.9	26	28	46	CLAY	0.05	<.15			
DIST SHALE	0-50	0-20	7.7	5.8	20.1	2.5	64.4	19.2	22	40	38	CL/L	0.07	<.15			
UNDIST SHALE	5-20	2-8	7.1	12	24.8	5.9	167	42.6	18	44	38	SC/L	1.65	.87			
UNDIST SHALE	5-30	2-12	7.6	18	29.5	35 4	282	49.5	24	40	36	CL/L	1.14	1.28			
UNDIST SOIL	0-90	0-30	8	0.28	2.6	0.6	0.7	0.6	88	6	6	SAND			0.69	0.46	54.6
UNDIST SOIL	0-15	0-6	8	0.32	7.4	2.1	0.9	0 4	88	8	4	SAND			0.69	0.56	66.2

SAR values found in undisturbed soil were much lower than values identified during wedge plot soil analysis. Native soil samples had SAR values of 0.6 and 0.4 while top dressing analysis ranged from 1.32 to 12.6. Close evaluation of analysis shows that there is some indication that migration of sodium is occurring from the disturbed spoils into the interface layer and upward towards the soil surface. Further evaluation and increased sample numbers would be necessary to determine this. Undisturbed shale samples had a much higher EC than graded or disturbed spoils, with EC's from two shale samples of 12 and 18 mmhos/cm and SAR values of 42.6 and 49.5. Recent samples, from undisturbed shale, exhibit high levels of sodium (Na) as compared to shale that has been disturbed. Sodium absorption ratio (SAR) found in the spoils and shale ranged from 19.2 to 49.5, with an average of 31.9.

Selenium was analyzed in five of the twelve spoil and shale samples for total and hot water extractable selenium. Three samples from disturbed shale indicate elevated levels for total and extractable selenium. Hot water extractable selenium had values of 0.13, 0.05 and 0.07 ppm and total selenium were all <0.15 ppm. Selenium samples from undisturbed shale were considerably higher with 1.65 and 1.14 ppm for the hot water extract and 0.87 and 1.28 ppm total selenium, respectively.

Soil fertility of sandy soils, as exhibited here, have an inherently low level of availability due to the low cation exchange capacity. Nutrient holding capacity of soils sampled had low levels of NO_3, P_2O_5 and dissolved K as indicated by Tiedmann, 1982.

CONCLUSIONS

As top dressing depth increased in the wedge plot, changes in species and life forms occurred. In areas of very shallow, less than 10 cm (4"), poor vegetative cover and diversity existed. Only 1 perennial and 3 annual grass species existed in this region. As top dressing depth increased from 10 cm (4") to 46 cm (18"), vegetative cover and species diversity was greatest. As Table 1, transects 7 to 21 details, perennial & annual grasses, forbs and shrubs were present within this rooting zone depth. Excessive depth of top dressing with sandy textured soils may not be beneficial to developing and establishing the most desirable plant community. The excessively deep top dressing may create a condition that is droughty and low in necessary nutrient requirements for plant growth and establishment.

Establishment of grasses and shrubs in arid vegetation zones require native plant selection that will tolerate environmental stress. It is imperative that when selecting species for land reclamation, one should take into consideration spoil and top soil chemical and physical characteristics and depth of topsoil. The potential vegetation community, based on site specific variances and species adaptability for community succession, should be part of the planning and reclamation process. Developing vegetation structure for a reclamation plan, by considering the above mentioned criteria, will encourage landscape stability and improved utilization.

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